ALLIS-CHALMERS Electrical REVIEW

First Quarter, 1951

Expanded Assembly Lines Increase CURVACORE Transformer Production

IT IS NOW EASIER to obtain *Curvacore* distribution transformers. Production facilities are expanded. You'll be able to take advantage of the inherent benefits of *Curvacore* transformers sooner.

Curvacore transformer design improvements give more performance for your distribution dollar. Cold rolled oriented steel strips have high flux carrying capacity and low hysteresis loss. The core steel is wound, shaped, annealed and cut into two turn lengths. Then each length is fed through the coil structure so that it retains its original core shape.

You benefit from these improvements:

1. 50% lower exciting current
2. Better ratio of losses
3. Improved short time thermal capacity
4. Size and weight reduced 15%
5. Regulation improved up to 15%

This wound core design provides a more efficient path for the magnetic flux, resulting in low exciting current. The *Curvacore* transformer has better thermal performance, too! Increased cooling area within the windings reduces the copper-to-oil temperature gradient, improves regulation and adds years to service life. Weight is reduced, making the *Curvacore* transformer compact, easy to handle and to install.

Former Advantages Retained

In addition to *Curvacore* transformer design you still get *Spra-Bonderized* tanks with 3-coat baked-on finish of alkyd-resinous paint; simplified high voltage angle bushings with handy chuck type connectors; sturdy tank construction; high quality craftsmanship throughout.

For more information about the *Curvacore* transformer, contact your local Allis-Chalmers district office or write Allis-Chalmers, Milwaukee 1, Wisconsin. A-3366

Typical core and coil assembly shown above. Present ratings of *Curvacore* transformers are 25 kva and below. Others will be available shortly.

Curvacore is an Allis-Chalmers trademark.

ALLIS-CHALMERS

THIS "SHOW WINDOW" installation contains controls for four 5,000-kw generators in a hydro-electric utility in the midwest. Companion 15-kv air blast switchgear is installed below the control room.

Duplex switchboards provide convenient centralized control of complex electrical networks in industrial and utility systems. Frequently used control switches and instruments mounted on the front panel simplify instrument reading. Protective relays, watthour meters and other less frequently used instruments are mounted on the rear panel. Door at each end provides safe, easy access for inspection and maintenance of instrument wiring.

Allis-Chalmers Staff Photo

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Electrical Review

Vol. XVI No. 1

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Issued quarterly. Subscription rates: U. S., Mexico, and Canada, $2.00 per year; other countries, $3.00; single copies, $1.00 in advance.

Address Allis-Chalmers Electrical Review, Milwaukee 1, Wisconsin.

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ALLIS-CHALMERS Electrical REVIEW

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Indexed regularly by Engineering Index, Inc.
Allis-Chalmers ELECTRICAL REVIEW is available to public and institutional libraries on microfilm from University Microfilms, 313 N. First St., Ann Arbor, Mich.

POWER for a *Modern* BLOOMING, BAR and BILLET MILL

by C. H. LEGLER*
Motor-Generator Section
Allis-Chalmers Mfg. Co.

Progressive, co-operative engineering adds another "first" to industrial progress.

THE WORLD'S FIRST CONTINUOUS seamless pipe mill recently placed in operation by National Tube Company at Lorain, Ohio, reflects the latest developments in the design and arrangement of equipment for blooming, bar and billet mills. Producing about 18,000 tons of two- to four-inch diameter pipe per month, the pipe mill's substantially constant tonnage of approximately 14 tons per hour is maintained regardless of the length, diameter or thickness of the finished product. Requiring only one size billet diameter to produce the variety of finished products, the mill is capable of delivering two-inch pipe in 142-foot lengths at a maximum speed of 1300 feet per minute.

Billets for the new pipe mill is supplied by one of the most modern blooming, bar and billet mills in the world. Diagrammed in Figure 1, the mill was engineered to roll stock from ingot to the various semi-finished products in a single heat. It has sufficient flexibility to roll several products simultaneously and to change from one product to another with minimum delay. In addition to supplying round billets for the new continuous seamless pipe mill, the mill also supplies round or square blooms, skelp slabs and billets for other finishing mills.

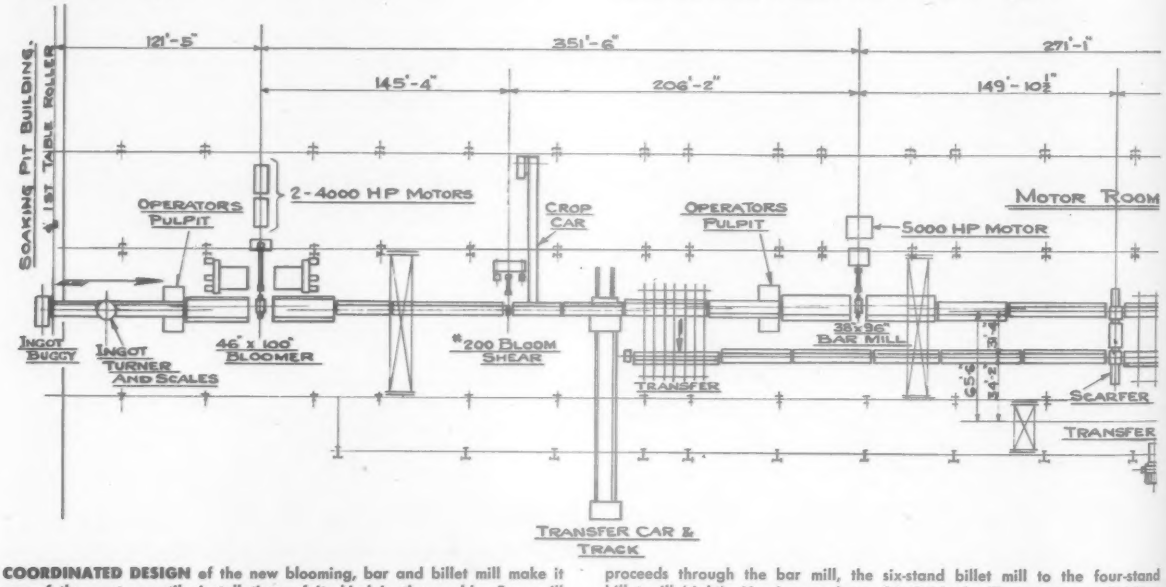
The blooming mill shown at the left in Figure 1[1] normally reduces a 32½-inch by 32½-inch ingot to a 15-inch by 15-inch bloom and occasionally to a 9-inch by 8-inch bar. Blooms are cropped, cut to length and then either delivered from the bar mill or transferred by transfer car and track to storage. Bars are transferred to a parallel mill line, by-passing the bar mill, for delivery to the six-stand billet mill.

Mills perform double duty

The bar mill is a two high reversing mill, very similar to the blooming mill but of smaller proportions, with rolls measuring 40 inches in diameter and 96 inches in length. Normally, it reduces the 15-inch by 15-inch blooms received from the blooming mill to 9-inch by 8-inch bars which are delivered by transfer to the six-stand billet mill line. Other products of varying sizes, both round and square, are delivered directly to storage for supplying other finishing mill equipment. In emergencies the bar mill can substitute for the blooming mill and roll directly from the ingot just as the blooming mill

* Ed. Note: Material was coordinated by Mr. Legler. His description of motor-generator details are inserted at various points throughout the article to present a logical "flow" of power.

[1] *Illustrations courtesy of National Tube Company, Pittsburgh, Pa.*



COORDINATED DESIGN of the new blooming, bar and billet mill make it one of the most versatile installations of its kind in the world. Four mill unit can roll many sizes of blooms, billets, rounds and skelp slabs with minimum roll changes. Rolling starts with the blooming mill (left) and proceeds through the bar mill, the six-stand billet mill to the four-stand billet mill (right). Varying products of individual mills converge to finishing facilities designed to operate independently or in any combination. Diagram shows schematic layout of the installation. **(FIGURE 1)**

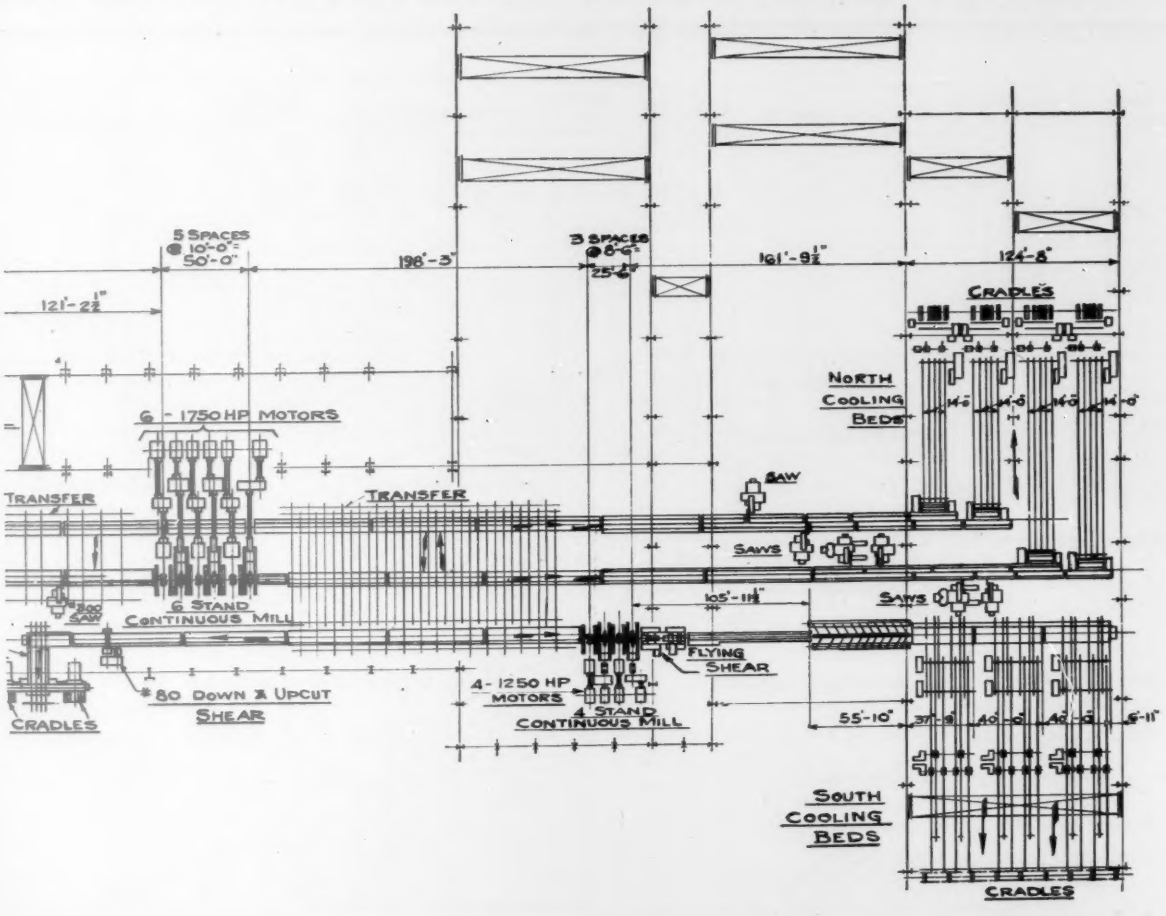
can take over rolling down to the products normally rolled on the bar mill in which case the bar mill is by-passed in delivering bars to the six-stand mill. Figure 2 shows a view from the delivery side of the bar mill.

Continuous rolling of the 9-inch by 8-inch bar received normally from the bar mill, sometimes from the blooming mill, is done in a modern and versatile six-stand billet mill. Its three vertical and three horizontal stands rest on 10-foot centers. The first, third and fifth stands are vertical and are constructed to accomplish the same reduction with the same powering as horizontal stands two, four, and six. The vertical stands use 30-inch by 48-inch rolls while 28-inch by 48-inch rolls are used on the horizontal stands. The two rolls of each stand are grooved to give a wide variety of semi-finished products including square billets, tube rounds, and skelp slabs most of which can be rolled with the same roll set-up. Product can be delivered directly for finish rolling in other mills or can be transferred to the parallel line for further reduction in the four-stand billet mill. A view from the delivery side of the six-stand mill is shown in Figure 3.

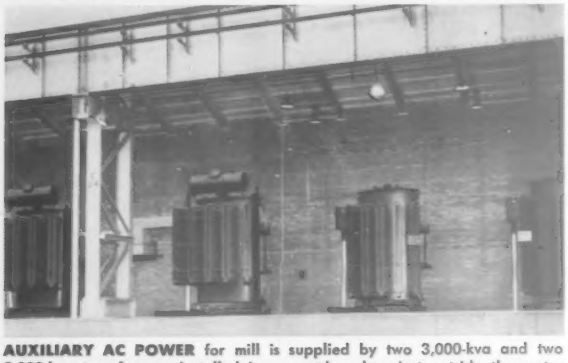
The four-stand billet mill is essentially of the same construction as the six-stand mill with number one and three stands vertical and two and four horizontal. Rolls in all stands have a 20-inch diameter and measure 36 inches in length. Normally, these take 4-inch by 4-inch or 4½-inch by 4½-inch billets from the six-stand mill and reduce them to tube rounds

BAR EMERGING from reversing bar mill is ready for surface conditioning in hot scarfer and subsequent cutting to length. Depending on product required, output from this mill either goes to stock for other mills or direct to billet mills for further reduction. **(FIGURE 2)**

ranging from 3¼-inch to 3¾-inch diameter or 2½-inch by 2½-inch billets, with other sizes possible. When the billet emerges from the four-stand mill, it has been reduced from the 32½-inch by 32½-inch ingot to these sizes without re-



SIX-STAND BILLET MILL combines features of hot strip mills with new features applied to bar and billet mills. Adjustable vertical stands permit quick change of rolling schedule with a common roll set-up. **(FIGURE 3)**

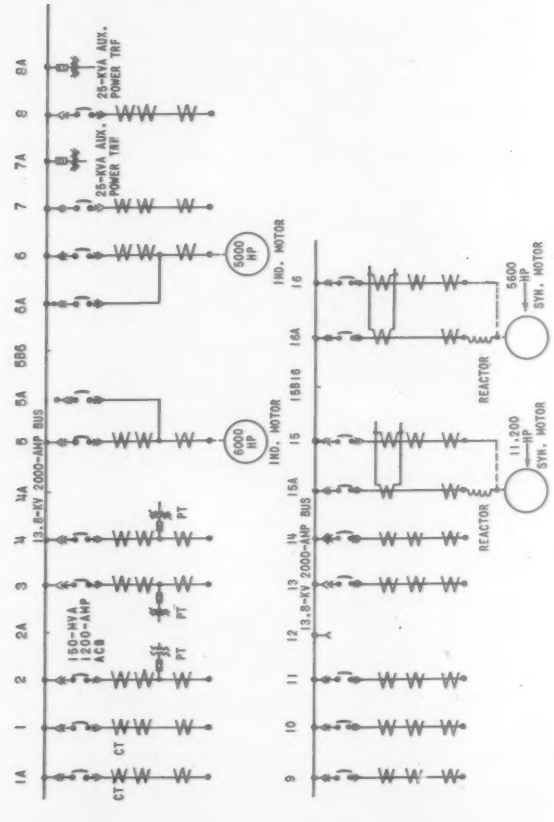


AUXILIARY AC POWER for mill is supplied by two 3,000-kva and two 2,000-kva transformers installed in an outdoor bay just outside the motor room and connected to 13,800-, 2300- and 480-volt switchgear. **(FIGURE 4)**

heating between any of the intermediate stages of rolling, resulting in high production rates and low rolling costs.

Electrical equipment for the mill consists of main drive motors and control with their supporting motor-generator sets supplied through 13,800-volt indoor metal-clad switchgear. Auxiliary power is supplied through outdoor distribution transformers supplying 2300-and 440-volt ac from the 13,800-volt system. Also fed from the 13,800-volt bus in the main switchgear are two mercury arc rectifier units supplying 250-volt dc mill supply. With the exception of the four-stand mill motors, the indoor equipment is housed in a common motor room which is ventilated with clean air under pressure.

The outdoor transformers are in bays just outside the motor room as illustrated in Figure 4 showing two 3000-kva, 13,800/2300-volt and two 2000-kva, 13,800/480-volt transformers. Another 3000-kva transformer is mounted in another bay. These standard oil-insulated, self-cooled, 55-degree C rise, three-phase, 60-cycle transformers are equipped with 2½-percent taps above and 2½-percent taps below normal in the high voltage winding. Power is received through the 13,800-volt indoor switchgear through cable terminating in junction boxes on the sides of the transformers. Low voltage terminals are throat-connected to their respective indoor switchgear through metal enclosed bus ducts. An outdoor substation supplies primary power to the mill and steps down purchased 60-cycle power from 138,000 volts to 13,800 volts.



SINGLE LINE DIAGRAM shows the schematic layout of the 13.8-kv, metal-clad switchgear which controls the incoming 13,800-volt power. Starting reactors are in the basement below the unit. **(FIGURE 5a)**

UNIT NO.	DESIGNATIONS	PROTECTIVE RELAYS											METERING EQUIPMENT											
		Time Delay Overcurrent	Inst. Overcurrent	Pilotwire Differential	Residual Ground	Time Delay Undervoltage	Bus Differential	Differential	Current Balance	Thermal Overload	Incomplete Sequence		Ammeter	Wattmeter	Recording Wattmeter	Watthour Meter	Recording Demand WHM	Bus Voltmeter	Incoming Line Voltmeter	Recording RVA Meter	Rec. Dem. Ammeter	DC Voltmeter	DC Ammeter	
1A	Future	X		X	X								X	X										
1	15,000-KVA Feeder	X		X	X								X	X		X	X	X						
2	Incom. Line No. 1	X	X	X	X								X	X					X					
2A	Metering Pot. Trf.																							
3	Incom. Line No. 2	X	X	X	X								X	X					X					
4	Incom. Line No. 3	X	X	X	X								X	X					X					
4A	Totalizing Metering					Δ	O								X	X	X	X		X				
5	6,000-hp Ind. Motor	X	X		X			X	X	X			X		X	X	X				X			
5A	Dynam. Braking																					X	X	
5B6	Dynam. Braking																							
6A	Dynam. Braking																					X	X	
6	5,000-hp Ind. Motor	X	X		X			X	X	X			X		X	X	X				X			
7	1500-KW Rectif. No. 1	X	X		X				X				X		X	X	X							
7A	Aux. Power Trf.																							
8	1500-KW Rectif. No. 2	X	X		X				X				X		X	X	X							
8A	Aux. Power Trf.																							
9	3,000-KVA Trf. No. 1	X	X		X				X				X	X		X	X							
10	3,000-KVA Trf. No. 2	X	X		X				X				X	X		X	X							
11	3,000-KVA Trf. No. 3	X	X		X				X				X	X		X	X							
12																								
13	2,000-KVA Trf. No. 1	X	X		X				X				X	X		X	X							
14	2,000-KVA Trf. No. 2	X	X		X				X				X	X		X	X							
15A	Starting Brk. } 11,200-hp																							
15	Running Brk. } Syn. Motor	X	X		X			X	X	X			X		X	X	X					X	X	
15B16	Field Application Equip.										X							X						
16A	Starting Brk. } 5600-hp																							
16	Running Brk. } Syn. Motor	X	X		X			X	X	X			X		X	X	X					X	X	

X Mounted on panel of corresponding unit. Δ Trips all outgoing feeder breakers.
O Trips all incoming and outgoing feeder breakers.

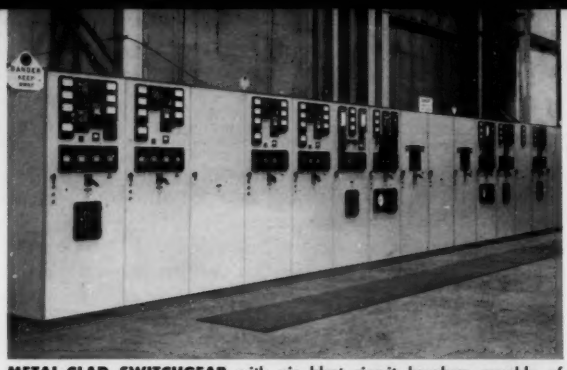
IMPORTANT PRIMARY relays for protecting the 13.8-kv switchgear are listed in this table. Recording and indicating meters were selected to provide all necessary operating data conveniently. **(FIGURE 5b)**

Flexible switchgear layout protects power supply and provides for future changes

by **JOHN BAUDE**
Switchgear Section
Allis-Chalmers Mfg. Co.

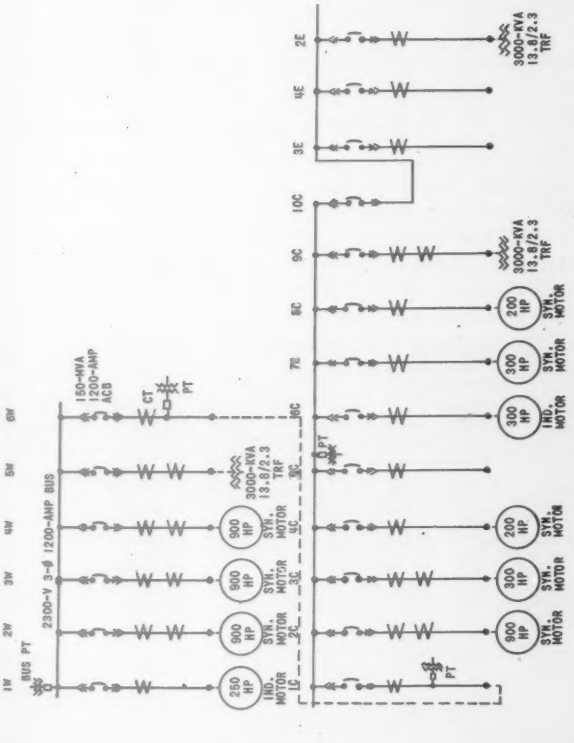
SINCE THE BAR and billet mill supplies the raw material for the new continuous seamless pipe mill, continuity of service is imperative. Switchgear lineup includes all the protective equipment necessary to assure maximum safety and dependability. To accommodate future variations in requirements, provision for the addition of matching units and the relocation of feeder units is included in the design.

At present nineteen 500-mva interrupting capacity 13.8-kv 1200-amp air blast circuit breakers are included in the indoor vertical lift switchgear lineup which feeds power to the mill motors and to the 13.8/480-volt and 13.8-kv/230-volt distribution transformers. The schematic layout of the switchgear is



METAL-CLAD SWITCHGEAR with air blast circuit breakers capable of interrupting 500,000-kva control the incoming power and distribute power for the motor-generator sets and rectifier transformers. **(FIGURE 6)**

BAR MILL MOTORS and motor-generator set for the 36-inch mill are protected by a 13-unit, 2300-volt metal-clad switchgear. The 480-volt lineup at left is used for lighting and auxiliary purposes. **(FIGURE 7)**



SCHEMATIC LAYOUT shows the lineup of the 2.3-kv switchgear which is connected to four transformers totalling 10,000-kva. These supply general purpose ac power for the mill. **(FIGURE 8a)**

UNIT NO.	DESIGNATIONS	PROTECTIVE RELAYS								METERING EQUIPMENT							
		Time Delay Overcurrent	Inst. Overcurrent	Thermal Overcurrent	Time Delay Undervoltage	Reverse Phase	Differential Relays			Ammeter	Bus Voltmeter	Incoming Line Voltmeter	Watthour Meter	Watthour Demand Indicat.	Recording WH Demand	Recording RWH Demand	
1W	250-hp Ind. Mot. M-G Set	X	X	X	X	X				X	X		X	X			
2W	900-hp Syn. Mot. F & B Tables	X	X	X	X	X	X			X			X	X			
3W	900-hp Syn. Mot. F & B Tables	X	X	X	X	X	X			X			X	X			
4W	900-hp Syn. Bloom Shear	X	X	X	X	X	X			X			X	X			
5W	Incom. Line 3,000-KVA Trf.	X	X				Δ			X		X				X	X
6W	Bus Tie						X					X					
1C	Bus Tie						X					X					
2C	900-hp Syn. Mot. F & B Tables	X	X	X	X	X	X			X			X	X			
3C	900-hp Syn. Mot. F & B Tables	X	X	X	X	X	X			X			X	X			
4C	200-hp Syn. Mot. Bar Mill	X	X	X	X	X				X			X	X			
5C	Peeler M-G Set Starter	X	X	X	X	X				X	X		X	X			
6C	300-hp Ind. Mot. Div. Saw.	X	X	X	X	X				X			X	X			
7C	300-hp Syn. Mot. M-G Set	X	X	X	X	X				X			X	X			
8C	200-hp Syn. Mot. M-G Set	X	X	X	X	X				X			X	X			
9C	Incom. Line 3,000-KVA Trf.	X	X				Δ			X		X				X	X
10C	Bus Tie																
3E	Saw Feeder	X	X							X			X	X			
4E	Saw Feeder	X	X							X			X	X			
2E	Incom. Line 3,000-KVA Trf.	X	X				Δ			X		X				X	X

Δ Differential relays mounted on 13.8-kv switchgear.

TABLE SUMMARY indicates all the protective relays and important metering equipment for the 2300-volt switchgear. Components are arranged for easy use and accessibility. **(FIGURE 8b)**

shown in Figure 5a, while Figure 5b shows the metering and relaying equipment. The 26-unit switchgear lineup is shown in Figure 6.

The starting reactors for the 5600-hp and 11,200-hp synchronous motors are located in the basement below the main switchgear and are connected by a metal enclosed bus. Surge protective equipment for motors is also mounted in the basement.

The 2.3-kv switchgear consists of two groups of units. The 13-unit group in Figure 7 has thirteen 150-mva interrupting capacity 1200-amp air magnetic circuit breakers while the other group which is not shown has six circuit breakers of the same type. The diagram, Figure 8a, and the table, Figure 8b, show the electrical arrangement of the equipment.

The 480-volt switchgear equipment is also shown on Figure 7. Its construction and appearance match that of the 2.3-kv switchgear equipment. The draw out circuit breakers in the low voltage lineup provide the necessary safety and easy accessibility.

Continuous excitation rectifiers give high conversion efficiency under varying load conditions

by W. E. GUTZWILLER
Electronics Section
Allis-Chalmers Mfg. Co.

THE 250-VOLT DC POWER for the auxiliaries of the No. 4 blooming mill is provided by two 1500-kw, heavy-duty, pump-evacuated excitron mercury arc rectifiers located in the center of the main motor room.

Each rectifier unit is designed to carry 100 percent rated current (6000 amp) continuously, 125 percent rated current (7500 amp) for two hours following 100 percent load, and 200 percent rated current (12,000 amp) for one minute following 100 percent load. Each unit consists of a 13.8-kv air circuit breaker unit, a rectifier main transformer, a six-pole anode breaker, a twelve-tube rectifier assembly, a rectifier control cubicle and dc switchgear.

The 13.8-kv vertical lift, drawout air blast circuit breaker forms part of the main 13.8-kv switchgear lineup previously described and illustrated in Figure 5.

High tension power from this switchgear unit is carried by cable to the two oil-insulated, self-cooled, outdoor rectifier transformers which are mounted on wheels and located on the north wall of the motor room in a semi-open transformer vault. The primary or ac windings are delta connected and provided with two plus and four minus 2½ percent no-load taps. The secondary or dc windings are connected six-phase (double wye) with an interphase transformer, with the six phases and neutral being brought out on the side of the transformer through a throat. A metal-clad cable duct connects each transformer throat to the motor room wall.

The rectifier transformers are designed for 60-degree C temperature rise when carrying 125 percent rated load for two hours following continuous operation at 100 percent rated load. Figure 9 shows a view of the two rectifier transformers.

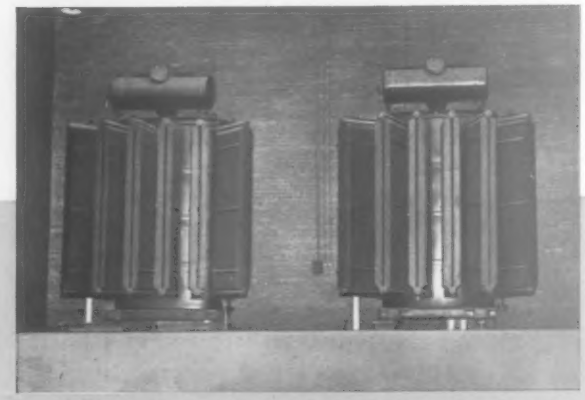
Equipment is centrally located

Figure 10 shows a view of the motor-room with the rectifier equipment in the background. The six-pole anode breakers shown in Figure 11 are located at the left and adjacent to the outside wall, through which the anode cables enter from above. These high speed motor-operated, frame mounted breakers are provided with reverse current trip and individual pole automatic reclosing.

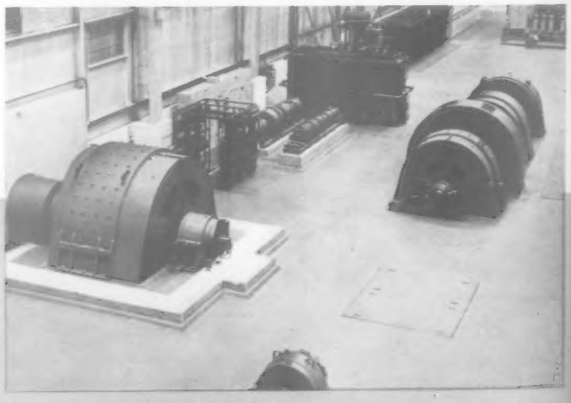
Six anode reactors are located in the lower part of each anode breaker frame. Pairs of rectifier tanks, connected to a common transformer phase, are paralleled through these reactors. Power is carried from the reactors by cables through the basement of the motor room into the rectifier frames.

Each rectifier frame contains 12 excitron tubes arranged in two groups, each two tubes wide and three tubes deep, with the evacuating equipment located between the two six-tube groups. The end facing the anode breakers carries a horizontally mounted, water-to-water heat exchanger, a motor-driven water circulating pump, immersion heaters, automatic temperature control and protection, forming a closed recirculating cooling system.

The control and protective circuits of the rectifier frame are carried to a terminal board at the right-hand end of each frame from where they are taken through an insulated throat into the control cubicle. Contained on the two front doors of the cubicle are the dc, phase control and vacuum indicating in-



STANDARD OIL-FILLED, self-cooled transformers in a semi-enclosed outside bay step down 13.8-kv line voltage for the 1500-kw mercury arc rectifiers. Primaries are cable connected to the ac switchgear. **(FIGURE 9)**



FREQUENT PEAK LOADS of the fast reversing bar mill motor are absorbed by the supporting m-g set flywheel (front). Rectifiers with their control and switchgear (rear) supply dc for the mill. **(FIGURE 10)**

struments, alarm annunciator, automatic voltage regulating and current limiting apparatus, control switches for ac and dc switchgear. The excitation supply selenium rectifiers, excitation control and protective apparatus for all rectifier auxiliaries are located inside the cubicle.

The dc switchgear, built in a continuous assembly and containing rectifier cathode breakers, tie and feeder breakers, is installed on the other side of the operating aisle opposite the rectifier cubicles. This switchgear, shown in Figure 12, is of the heavy duty, semi-high speed, single-pole, metal-enclosed, stationary type with disconnecting switches in both the positive and negative of each circuit.

Viewed from right to left, the arrangement of the compartments in this breaker board for this particular installation is:

1—DC bus tie, 8000 amp negative disconnecting switch
1—DC bus tie, 8000 amp positive breaker with disconnecting switch
2—DC feeders, each 2000 amp with positive and negative disconnecting switches
1—No. 1 rectifier cathode breaker, 8000 amp with positive and negative disconnecting switch
5—DC feeders, each 2000 amp with positive and negative disconnecting switch
1—No. 2 rectifier cathode breaker, 8000 amp with positive and negative disconnecting switch
3—DC feeders, each 2000 amp with positive and negative disconnecting switch

The ac auxiliary power for each rectifier unit is supplied from a 25-kva, 13,800/230-volt, three-phase, 60-cycle transformer located in the 13.8-kv switchgear structure with the necessary primary and secondary protective devices.

The dc breakers are closed and tripped from the 125-volt station battery.

The anode breakers are closed by dc motor and the reverse current trip devices also utilize battery power for polarization.

Semi-automatic operation of equipment

Each rectifier unit is started by closing the 13.8-kv ac breaker by a control switch on the rectifier control cubicle. The closing of this breaker automatically starts up the rectifier auxiliaries, then the anode and cathode breakers are closed by their respective control switches on the rectifier cubicle. A reverse sequence applied to the same devices shuts the unit down.

In case of an arc-back (failure of rectifying action) in a rectifier tube, only that pole of the anode breaker carrying the reverse current of the faulted tube trips and attempts to reclose three times at fixed time intervals of a few seconds. If successful reclosure is made, the faulted tube is restored to service. If the third reclosure is unsuccessful, however, then all poles of the breaker are tripped and the unit is shut down. This individual pole reclosing scheme localizes the fault to the phase on which the arc-back occurred and leaves the remaining phases undisturbed unless the phase fault continues. Hence the rectifier unit continues to operate while the disturbed phase is temporarily disconnected.

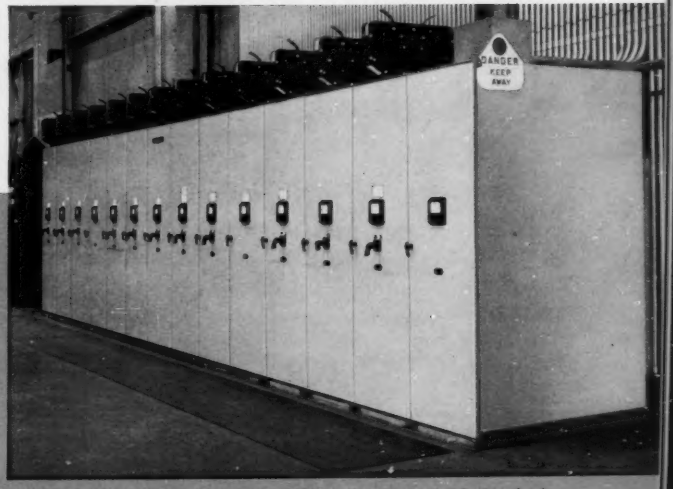
While the high speed anode breakers have many desirable protective features, and contribute greatly to the continuity of rectifier service, they are usually not essential for rectifier installations of this type. In this instance, however, it was necessary to operate, in emergency, the two 1500-kw rectifiers, supplied with 60-cycle purchased power, in parallel with three 750-kw synchronous converters operated from the steel mill's own 25-cycle power system. These converters are located in the No. 3 blooming mill substation which is about 300 feet from the rectifier substation. It is obvious that when operating rectifiers and converters in parallel the 25- and 60-cycle power systems are tied together electrically through the 250-volt dc tie-line. An arc-back in the rectifier would result in appreciable back-feed by the converters and may cause flash-overs on the commutators. High speed anode breakers were installed in order to prevent disruption of 250-volt dc service and possible damage to the converters under such conditions. They disconnect the faulted rectifier tube before the reverse current from the parallel converters reaches dangerous proportions.

Because of the importance of maintaining the rectifier load in the continuous operation of the No. 4 blooming bar and billet mill, and also because of the paralleling requirements with the 25-cycle converters, each rectifier was equipped with a current limiting regulator which reduces the rectifier output voltage by means of phase control when the load reaches a critically high value. The load current at which these regulators start to act is adjustable between 125 percent and 200 percent load.

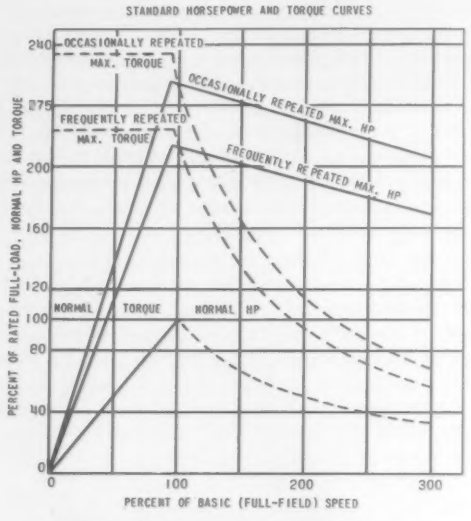
Drive incorporates special features

The main mill drive motors and their supporting motor-generator sets are specially designed to withstand the constant

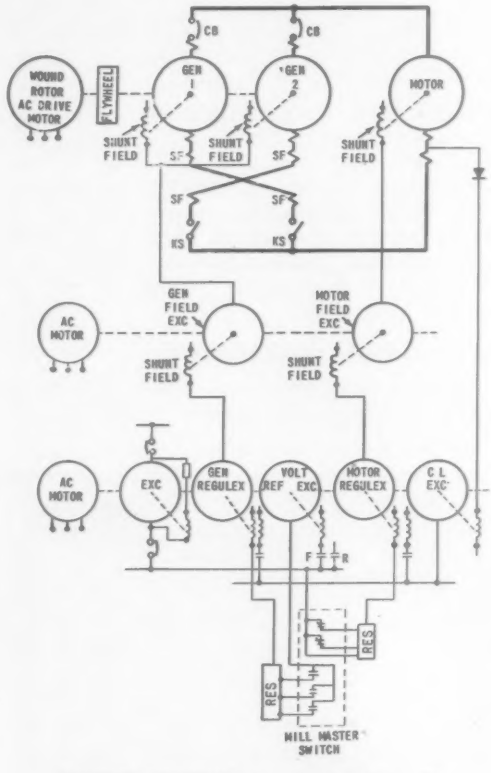
MERCURY ARC RECTIFIERS, rated 1500-kw, provide 250-volt dc power for the mill. Rectifier tanks, evacuating and cooling equipment form a factory assembled and wired unit for easy installation. **(FIGURE 11)**



SWITCHGEAR LINEUP illustrated above contains the cathode, feeder and tie breakers for protecting and distributing the 250-volt dc power from the two 1500-kw rectifiers to the mill auxiliaries. **(FIGURE 12)**



DESIGN INNOVATIONS in the 5,000-hp bar mill motor provided the specially suited characteristics for fast reversing service shown above. **(FIG. 13)**



CONTROL SEQUENCE for reversing hot mill shown schematically is actuated by the mill master switch. Heavy line is primary circuit. **(FIG. 14)**

and usually heavy wear and tear of rolling mill service. Class B insulation is used throughout.

Although the ring oiling bearings are capable of self lubrication, they are fitted for flood lubrication from an external oiling system. Each motor-generator bearing is fitted with a small motor-driven high pressure oil pump mounted on the motor-generator base. These supply oil under sufficient pressure to raise the shaft in the bearing on starting to make certain that a film of oil is re-established after it has been squeezed out by the weight of the shaft during a prolonged shutdown. This reduces the starting friction considerably, thereby reducing the inrush current required by the driving motor on starting. The high pressure oil starting pumps operate only during the starting period and are automatically cut out when the motor-generator is up to speed.

A separate forced-oil lubricating system is provided for the bar mill motor and its motor-generator set. Another similar system is provided for the six-stand mill motors, their supporting motor-generator set and the supporting motor-generator set for the four-stand mill motors. Because they are located on the side of the mill opposite the motor room, the four-stand mill motors have their own lubricating system. Ventilating air for cooling is taken from the motor room through louvred or perforated end covers, passed through the machines and discharged downward through solid end covers on the commutator ends of the dc machines and through the bottom of the stator yoke of the ac machines. Ventilating air for motors driving the four-stand mill is passed from the motor room through a tunnel and discharged upward into the mill atmosphere.

Bar mill designed for fast reversal

Figure 10 shows the bar mill portion of the motor room with the main drive reversing motor at the left and the flywheel motor-generator set at the right. The motor is rated 5000 hp, 65/130 rpm, 700 volts dc, 50 degrees C rise continuously, with momentary loading characteristics as shown in Figure 13. It can reverse from its 65-rpm base speed forward to base speed reverse in two seconds and from full speed, 130 rpm, forward to full speed reverse in five seconds. A thrust bearing on the coupling end protects the motor from end thrust which might occur as the result of an angular break in the long spindle connecting it to the mill or from mill thrust toward the motor. The mill is driven through a 38-inch pinion stand and delivers a maximum speed of 1360 feet per minute with the motor running at 130 rpm.

The supporting motor-generator set consists of two 2000-kw, 700-volt, 514-rpm generators driven by a 5000-hp, 13,800-volt, three-phase, 60-cycle wound rotor induction motor, and a 142,500-hp second flywheel. Generators and motor are rated at 50 degrees C rise continuously, good for 275 percent peaks from the generators at a speed corresponding to 15 percent slip of the induction driving motor. The cycle of operation is such that peak loads come at such intervals and duration as will allow the flywheel to be brought up to speed by the induction motor previous to being called upon to give up energy by slowing down under peak loads. Thus the induction motor can be made to draw lower and more constant current from the ac system than the fluctuating output of the generators would otherwise allow. When the set is shut down, the stored energy in the flywheel keeps it coasting for a relatively long period of time. Required braking is done by applying direct current to one phase of the induction motor primary

from a separate small dynamic braking exciter through a dynamic braking circuit breaker interlocked mechanically with the running circuit breaker in the switchgear lineup. A zero speed switch on the end of the shaft prevents accidental reverse rotation of the set.

Coordination of control and motor design necessary for continuous rolling

by R. M. PEEPLES
Control Section
Allis-Chalmers Mfg. Co.

MODERN CONTROL of the large reversing bar mill is shown schematically in Figure 14. The two 2000-kw generators with series fields cross-connected for load division supply the 5000-hp, 700-volt motor. Two high speed, high capacity circuit breakers protect this primary loop. Both the mill motor and the generators receive excitation from separate exciters which are designed to provide the necessary field current and, in addition, supply extra kw capacity to provide a forcing voltage to move the heavy fields of both generator and motor as quickly as possible. To minimize their inherent time delay the exciters were made of laminated construction. Individual high speed *Regulex* exciters supply excitation for the mill motor exciter and for the generator exciter. Two small exciters provide the voltage and current reference sources.

A mill master operated by pedals actuates the entire control sequence, providing a sequence of contact closing as the foot is depressed and operation of contacts for forward and reverse operation. The mill master and a control cabinet, mounting circuit breaker control and indicating lights, comprise the entire control normally placed at the disposal of the operator for this type of mill. In this particular instance a special mill spotting control was added. A cabinet mounted switch in the pulpit energizes a clutch on the end of the motor shaft which engages a dc position indicator showing the operator the position of the shaft key by means of a pulpit located indicator. With the normal control cut out and using the spotting control, the operator may slowly turn the mill and stop it with the shaft at the most desirable position for a roll change.

When the foot control is in the normal position, the *Regulex* exciters hold full field on the mill motor and near zero voltage on the generator. Depressing the pedal establishes a forward or reverse voltage on the generator reference exciter and, by successive closing of master switch contacts, raises the reference voltage to cause the *Regulex* exciter to bring up the generator voltage. Subsequent master switch contacts cause the motor *Regulex* exciter to weaken the mill motor field and to bring the motor up to full speed. Should the current exceed a safe value during this acceleration, current limit fields energized through the current limit exciter slow down the Regulex exciters to limit current buildup to a preset ceiling. This action takes place on the generator *Regulex* exciter while the generator voltage is being built up and on the motor *Regulex* exciter while the motor field is being changed.

Deceleration is obtained by reversing the foregoing operation, while continued deceleration through zero and into reverse comes about by reversing the potential called for by the generator reference exciter. The mill accelerates to speed in the reverse direction in the same manner as it did in the forward direction. Proper sequencing of the motor and generator current limit and the directional contactors is adjusted by a generator voltage relay, a motor field current relay and a zero speed relay. As a result, full-over forward to reverse operation is smooth and easy. Maximum torque per ampere is always used, and the fastest possible reversing time is obtained with minimum strain on the electrical apparatus.

Coordinated design vital for billet mills

Design of the electrical equipment for the six- and four-stand billet mills involved coordination between motor and control designers on several relatively new problems since the continuous rolling of large billets in close coupled, individually driven mills had little precedent in the industry. Continuous hot mills for rolling strip and the close coupled tube and rod mill afforded the related installations on which the necessary similar experience was available.

The product of the billet mill being of considerable cross-sectional area and the distance between stands small, there was every likelihood that considerable torque could be transmitted between drives. The unfavorable effect that stretch might have on the product, and the possibility of overloading a drive motor precluded exerting too much pull on the billet. On the other hand it was even less desirable to have a particular mill shirk its load and tend to create a loop behind it. Where the comparable strip or rod mill tolerated looping or even encouraged rolling with loops, the mechanical construction of the billet mill practically prohibited formation of loops. Accurate guides into the roll bites on this type of mill were necessary. Therefore, a discrepancy in speed correspondence of adjacent stands sufficient to bend a billet of several square inches cross-section tends to create a condition where destruction of mill parts is imminent. Jamming in the roll bite, or piling up of material between stands could not be tolerated, not only because of the possibility of destruction but because of the time and labor expended in clearing cobbles between stands.

The problem, therefore, was to devise a drive which would enable the operator by simple movements to preset each mill accurately to the speed at which the material would be delivered. Since these settings would be necessarily performed while the motors were at no load, the motors had to be stable during the transition from no load to the loaded condition. Consequently, the motor no load to full load speed variation had to be held to a minimum. In addition, a substantially constant load regulation had to be held over the entire speed range of the motor. Safe stopping was an additional specification.

Obviously, a speed regulator applied to each motor might have been adequate to hold flat speed under all conditions; but to obtain a justifiable result with speed regulators, high speed compensating means and accurate high speed regulators would have been necessary. These did not appear justifiable economically. It was decided, therefore, to apply a hot strip mill type of control to this application and depend on the motors themselves for the desired transient and regulation

characteristics. This resulted in special design and testing of motors to assure maximum inherent stability consistent with the economics involved. Selecting duplicate ratings for the stands of each mill contributed to their successful application by this procedure.

Safety features protect motors

The six-stand billet mill motor room area having six individual mill motors on the left and their supporting motor-generator set on the right is shown in Figure 15. The control panel is in the background. Each motor is rated 1750 hp, 300/600 rpm, 600-volt dc, rated at 40 degrees C continuously, 55 degrees C at 125 percent load for two hours, and no injury at 200 percent load for one minute occasionally applied.

Because of the long spindle shafts and the possibility of damage that could be done to a motor from thrust resulting in case of an angular break in a spindle, each motor was provided with a thrust bearing on the coupling end. Direct mill thrust was not probable since the mill is provided with gear units which absorb such thrust without transmitting it to a motor. The gear ratio is designed to reach a delivery speed from the mill of 346/692 feet per minute.

The motor-generator set has four 2000-kw, 600-volt generators connecting to a single bus which feeds the motors. The driver is a synchronous motor rated 11,200 hp, 13,800 volts, three-phase, 60-cycle, 95 percent pf with windings braced for full voltage starting. Starting is actually done by reduced voltage through a line reactor located under the switchgear lineup. Overload rating and temperature rise corresponds to that of the motors which the set supports. Not shown but off the bottom of the illustration and in line with this set is the four-stand mill motor-generator set which has two generators duplicating those of the six-stand set and driven by a 5600-hp, 95 percent pf synchronous motor also employing line reactor starting. Both sets run at 514 rpm. The four-stand mill motors are each rated 1250 hp, 400/800 rpm, 600 volts. Their construction differs from that of the six-stand motors only in that their ventilating covers are arranged for up-draft instead of down-draft ventilation. They are geared to the mill to attain a delivery speed of 430/860 feet per minute. A view of these motors and the mill they drive is shown in Figure 16.

Parts and machines were duplicated wherever possible to reduce the inventory of spares. Thus bearing sizes throughout the mill were minimized in number and type resulting in some bearings being larger than normally required. Duplication of machines cut down the number of spare parts required and even made it feasible to carry spare armatures for the four- and six-stand mill motors and generators.

A 600-volt mill bus constructed in the motor room basement carries the dc load from the generators to the motors. A circuit breaker in the positive and negative lead of each generator is located near the generator foundation and the generator leads run through these breakers to a widely separated positive and negative bus. The bus in turn runs the shortest possible distance along the motor lineup and is tapped off at each motor foundation to run through another positive and negative breaker to connect to the motor terminals. The high speed heavy duty steel mill type breakers used were rated at 750 volts with an interrupting capacity of 250,000 rms amperes. High speed rate of rise trip coils on each breaker provided maximum protection for the bus and motor installation.

Centralized controls aid operation

Generator excitation is obtained by a separate exciter which supplies all or any number of generators used on the bus. The excitation is automatically connected to any generator field when its line breaker is closed. The breaker closing system is interlocked in the standard hot mill manner to prevent closure of any breaker unless the bus voltage is zero. A *Regulex* exciter controls the excitation of the generator exciter to a constant voltage from zero to 600 volts. A motor operated rheostat calibrates the *Regulex* exciter to the voltage desired and also provides a standby means of controlling generator excitation manually.

Knife switches and control contactors are mounted on a duplex switchboard on the mill floor. Control switches and instruments are mounted on the steel front of the switchboard to provide a control center for this particular mill. A remote switch at this point starts the mill motor-generator set and also the exciter and *Regulex* exciter motor-generator sets. Control excitation is adjusted and switched on one panel. Generator circuit breakers are closed at an adjacent panel. One switch enables the operator to lock out all mill operation of the control, while a second enables him to check operation of the generator control and make necessary adjustments. Generator exciter and motor load meters indicate mill condition on these operating panels.

SIX-STAND BILLET MILL is driven by six 1750-hp, 300/600-rpm, 600-volt dc motors. These are powered through variable voltage control by a five unit motor-generator set consisting of four 2,000-kw dc generators driven by an 11,200-hp, 13,800-volt synchronous motor. **(FIGURE 15)**

FOUR-STAND BILLET MILL, similar in design to the six-stand mill, is driven by four 1250-hp, 400/800-rpm, 600-volt dc motors supported by a three unit m-g set. The two generators, duplicating those of the six-stand m-g set, are driven by a 5600-hp synchronous motor. **(FIGURE 16)**

Operating controls mounted on an elevated pulpit desk close to the mill enable the operator to close the motor circuit breakers by individual control switches. A speed control switch on the pulpit operates the *Regulex* exciter motor-operated rheostat and recalibrates the *Regulex* exciter circuit to raise the generator bus voltage gradually and to accelerate the mill motors to the desired operating voltage. An individual switch for each motor controls a motor operated field rheostat which changes the motor speed to approximately the desired value. Precise speed adjustments are then obtained by using a manual vernier field rheostat located beneath the pulpit and controlled from the desk by a chain drive.

Mill adjustment is judged by the operator from ammeter and speed indicator readings on each drive and from a voltmeter connected to the mill bus. A pushbutton which trips out all circuit breakers provides emergency stopping for the mill. Provision was also made to trip all motors off the bus if any one should trip for any reason. This was done to minimize the possibility of damage in case of a cobble.

An extra set of meters which register the speed differential between the drives on an expanded scale were provided to facilitate critical speed adjustment. Other concessions included the addition of high grade speed indicators and the incorporation of additional range into the vernier field rheostats.

During the initial runs on the mill the speeds on the individual stands were set to meet a precalculated schedule by hand tachometers. Since the motors were stable and possessed a small percentage of droop, it was a simple matter to meet the setup for the first billet successfully. Torque transmitted through the billet was perfectly apparent by observation of the motor ammeters at the beginning and end of the piece. Small readjustments of the motor fields quickly attained a speed setup which allowed each motor to pick up only its rolling load without putting anything into tension between stands.

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Packaged Bus Protects ELECTRICAL CONDUCTORS

by J. W. TIMMERMAN
Switchgear Section
Allis-Chalmers Mfg. Co.

Metal-enclosed bus eliminates need for overhead lines and cables for connecting component electrical units.

CONDUCTORS FOR CONNECTING the component parts of an electrical installation may be generally classed as either cable, overhead lines or bus bars. With the growing trend toward higher kva ratings bus bars and particularly metal enclosed bus have been increasing in popularity.

In metal-clad switchgear which has become the accepted standard for electric power switching, metal enclosed conductors are designed to afford maximum protection to personnel, simplify installation, and improve appearance. Since the metal enclosed bus is shipped ready to install, the installation does not call for any specialized skill.

While the results of standardization of metal enclosed switchgear are well understood, the application and terminology of metal enclosed bus are not too well known. In the belief that familiarity with the various types of bus may reveal their many application possibilities, this article will present a brief outline of the various types of bus now available and their accepted ratings.

Figures 1 and 2 show two types of metal enclosed switchgear with metal enclosed bus units. Figure 3 shows a typical open construction installation.

Three types available

There are three types of metal enclosed bus as defined in Switchgear Standards for connecting units of electrical equipment. These are the non-segregated phase, the segregated phase and the isolated phase types. All three differ in design and application. The non-segregated phase bus is usually built for voltage ratings of 600 to 13,800 volts, inclusive. The term "non-segregated" means that all conductors will be in a common enclosure with no barriers between phases. Conductors may be insulated or uninsulated. The illustrations in Tables 1 and 2 show typical cross sections of non-segregated construction and the usual ratings for which each type is built.

Table 1 is for applications not exceeding 600 volts and corresponds in construction to the low voltage cubicle equipment using air circuit breakers. The bus bar conductors in this case are bare and are mounted on phenolic insulators.

Table 2 shows the construction and lists the ratings usually used for applications above 600 volts and not exceeding 13,800 volts. This bus duct corresponds in construction to metal-clad equipment using vertical lift air magnetic, compressed air or oil circuit breakers. Generally, it consists of conductors covered with phenolic insulation and mounted on

GROUPS OF SWITCHGEAR UNITS are conveniently tied together with metal enclosed bus which eliminates the need for bushings, potheads and heavy cable installation. **(FIGURE 1)**

METAL-ENCLOSED BUS provides a neat appearance, safety and erection convenience. Non-segregated bus duct protects the transformer connections on this outdoor substation. **(FIGURE 2)**

SPECIAL STRUCTURES must be built at the installation to support the overhead open type bus used with this 15-kv to 4160-volt substation and feeder units. **(FIGURE 3)**

insulating phenolic supports. Bars in this type of equipment are insulated principally to maintain a relatively high dielectric strength level for the equipment with small air clearances and consequent minimum space requirements. A bus of this construction is usually built for through current ratings corresponding to those for breakers used in vertical lift switchgear.

Table 3 covers segregated phase bus and isolated phase bus having voltage ratings ranging from 14,400 to 34,500 volts and with through current ratings comparable to breakers of these voltages. In the segregated phase units each phase is completely enclosed by metal as illustrated in diagram a of Table 3. The solid metal barrier between phases separates or segregates the phases. The term "isolated" means that each phase is independently housed in metal as shown in Table 3, diagram b and has no enclosing covers in common with another phase. The construction of the segregated and isolated bus corresponds to that of station type cubicles using either air blast or oil breakers. As a rule porcelain is used for the conductor supports and air and porcelain constitute the necessary insulation. The space required, therefore, is greater than would be taken by the non-segregated construction.

The bus designs shown in Table 3 are for central station or concentrated power applications where the service voltages will range from 10,000 volts and up. Although this class of equipment has been used in ratings up to a maximum of 34,500 volts, these ratings are not included in Table 3 because they are seldom required. The limitations of 14,400 and 23,000-volt bus are shown. These maximum voltage limitations can be exceeded provided the system is adequately grounded and surge voltage limiting equipment is employed to hold voltage surges reasonably below the basic insulation level (BIL) rating of the equipment.

System affects bus choice

Ratings of the segregated and isolated bus structures shown in Table 3 are the same in every respect. The difference is in the construction of the enclosures resulting in greater space requirement and cost for the isolated phase type. Both types encase each phase in grounded metal and as compared to non-segregated phase construction are justified on high powered circuits in that any fault within the bus must involve ground thus avoiding ungrounded and, consequently, unlimited phase-to-phase fault currents.

Compared to the segregated phase bus, isolated phase construction is justified where ground currents are virtually unlimited and can reach a magnitude which could rupture or

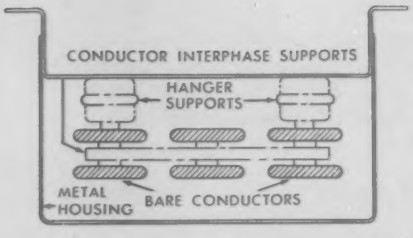


TABLE 1

MAXIMUM SERVICE VOLTAGE	INSULATION TEST VOLTAGE		CONTINUOUS CURRENT RATING (AMP)	MOMENTARY CURRENT RATING AMPERES			
	KV 60-C	IMPULSE (BIL)		25,000	50,000	75,000	100,000
600	2,200	None	600	X	X		
			1,200	X	X	X	
			1,600	X	X	X	X
			2,000	X	X	X	X
			3,000		X	X	X
			4,000		X	X	X
			5,000			X	X
			6,000				X

burn through the metal housing to involve the second or third phases and extend the damage before protective circuit breakers could interrupt the current. The speeds of modern relays and circuit breakers in conjunction with the limited ground currents found on the majority of high power systems usually provide an assurance factor sufficiently high to make the use of the more economic segregated construction adequate.

The choice of bus type for any voltage, non-segregated, segregated or isolated phase, is determined usually by the type of associated switchgear chosen for the application. In almost any case, standard buses are planned to provide a choice that will satisfy the desired coordinated result. Unusual conditions, however, sometimes legitimately require deviations from standard bus construction and ratings as shown in the tables. A general understanding of the terminology, the various voltage, insulation, and current rating limitations and reasons for the different standard constructions will enable engineers to select metal enclosed bus with an economy in keeping with requirements of the overall system planning.

STATOR YOKE shown on a 40-ft boring mill is one of two 82,500-kva, 1.0-pf, 180-rpm vertical synchronous generators being built for Hoover Dam. To be driven by 115,000-hp, 480-ft head hydraulic turbines, units will be the largest complete hydro-electric machines built by one firm.

A-C Staff Photo

GLOSSARY

1. Maximum Service Voltage — line-to-line nominal system voltage.
2. Insulation Test Voltage (60-cycle) — voltage the equipment will stand for one minute without breakdown.
3. Insulation Test Voltage — Impulse (Basic Insulation Level) — the surge voltage as defined by the American Standards Association which the equipment will withstand.
4. Continuous Current — continuous load the equipment will carry without exceeding the allowed temperature rise.
5. Momentary Current — maximum rms value of momentary current (initial fault current) which the equipment will carry without thermal or mechanical (magnetic) damage.

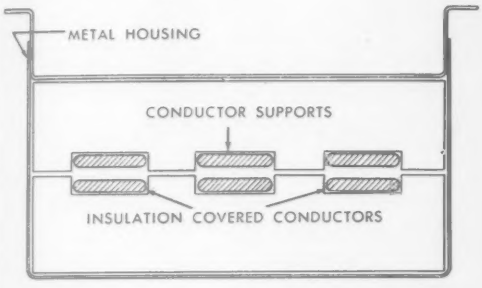
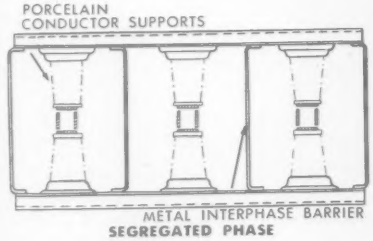
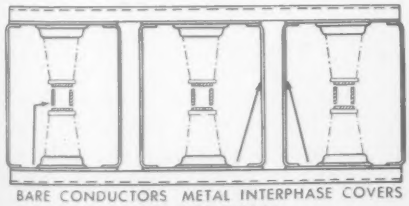


TABLE 2

MAXIMUM SERVICE VOLTAGE	INSULATION TEST VOLTAGE		CONTINUOUS CURRENT RATING (AMP)	MOMENTARY CURRENT RATING AMPERES			
	KV 60-C	IMPULSE (BIL)		20,000	40,000	60,000	70,000
4,160	19,000	60,000	1,200	X	X	X	
			2,000	X	X	X	
			3,000		X	X	
13,800	36,000	95,000	1,200	X	X		
			2,000	X	X	X	X
			3,000		X	X	X



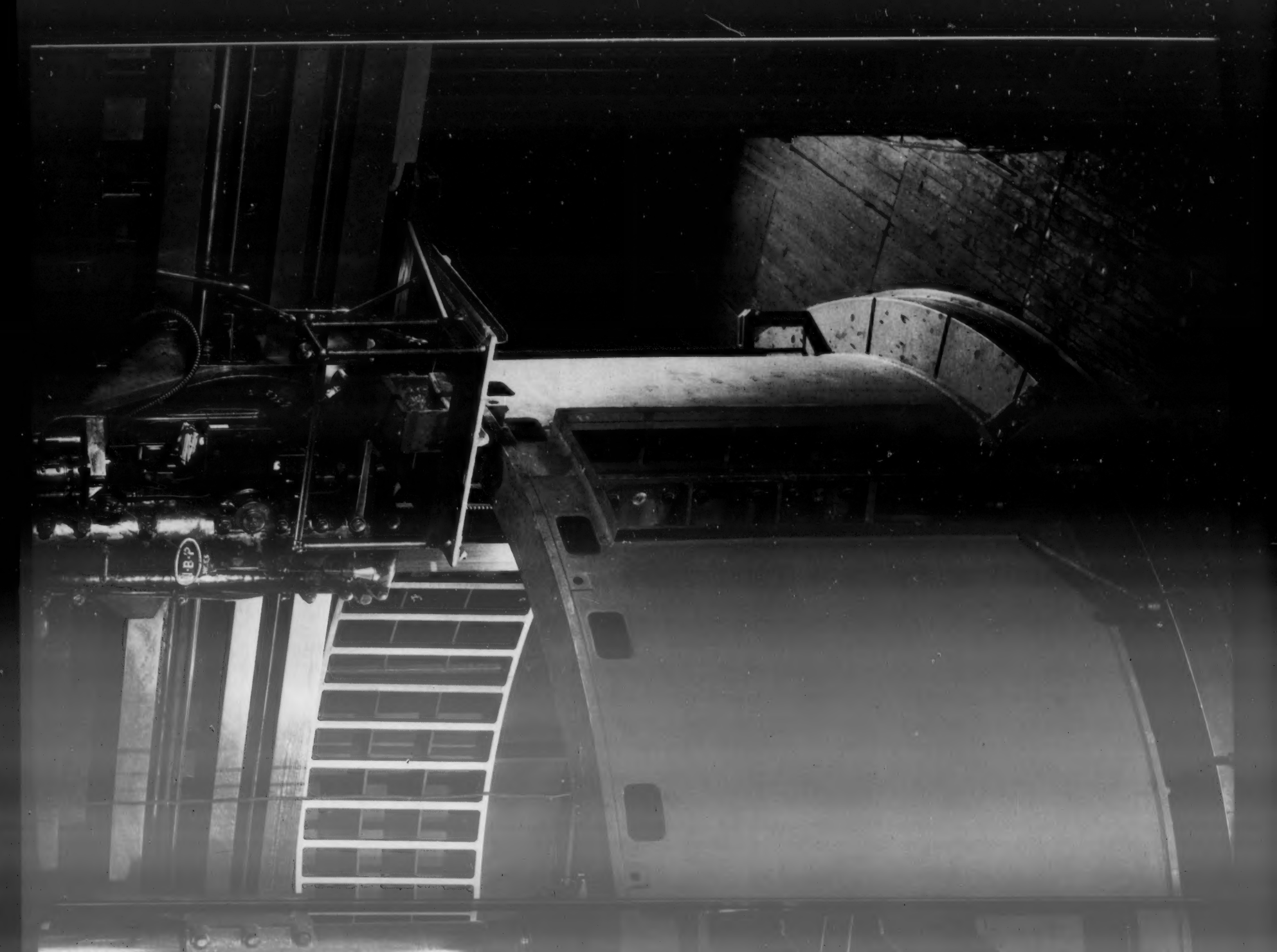
SEGREGATED PHASE



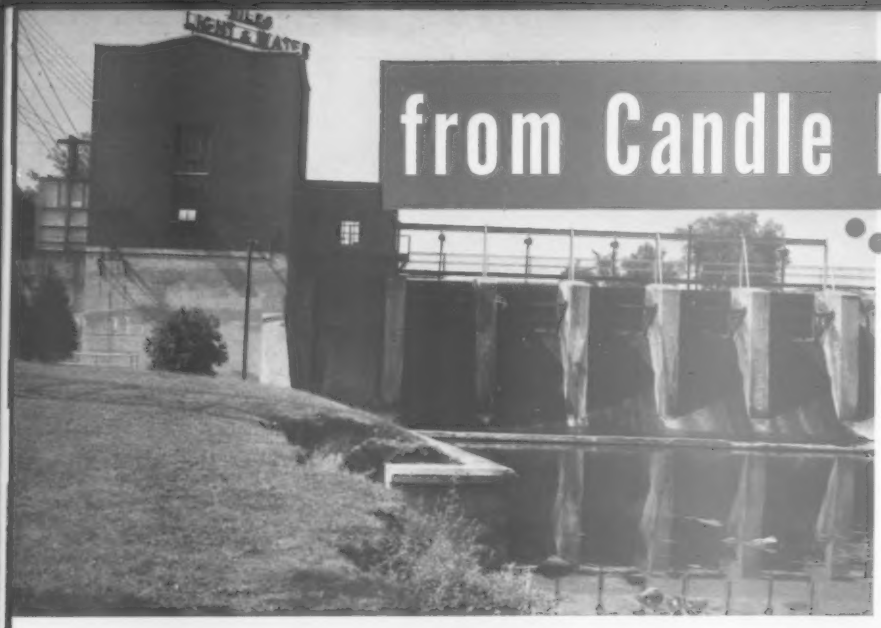
ISOLATED PHASE

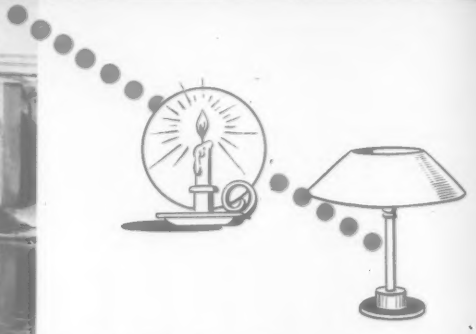
TABLE 3

MAXIMUM SERVICE VOLTAGE	INSULATION TEST VOLTAGE		CONTINUOUS CURRENT RATING (AMP)	MOMENTARY CURRENT RATING AMPERES		
	KV 60-C	IMPULSE (BIL)		77,000	115,000	190,000
14,400	50	110	1,200	X	X	
			2,000	X	X	
			3,000	X	X	
			4,000	X	X	
			5,000		X	X
23,000	60	150	1,200	X	X	
			2,000	X	X	
			3,000	X	X	
			4,000	X	X	
			5,000		X	X



from Candle Power to KW





QUAINT LANDMARK provides economical power to meet vastly increased residential, commercial and industrial needs. **(FIG. 1)**

by **ROBERT LOEWE**
Switchgear Section
Allis-Chalmers Mfg. Co.

and

ROY ROBINSON, Manager
Board of Public Works
Niles, Michigan

Modernization investment reduced operating costs, increased old plant's efficiency and capacity, and reduced purchased power cost.

SMALL HYDRO-ELECTRIC PLANTS need not be relegated to reminders of the early days of electrical power generation. With modern equipment and procedures the great majority of them can be converted into sources of additional revenue through savings in labor and increased operating efficiency. This is especially true in the light of today's vastly increased and steadily rising demand for electric power for industrial and domestic needs. A typical example of using available hydro capacity in peak periods to reduce the maximum demand for the per kilowatt hour cost of purchased power is the 58-year-old plant serving the city of Niles, Michigan.

Like many other plants the Niles hydro station was built in the days when there were few, if any, transmission line networks to provide needed power. Water power was used because it was the most readily available and economical source of electrical energy. This is no longer true today when the problem of supplying new areas occurs, since in most cases it is best to depend on large scale power production by buying power from the nearest large utility.

Because of the constantly rising demand for power, the old hydro plants are a godsend to many communities in reducing the cost of electric power. Utility rate structures are arranged so that the total rate per kilowatt hour is made up of a basic charge per kilowatt hour determined by the number used per billing period and a demand charge based upon the peak demand during that same billing period. It is obvious that the total energy charge can be greatly reduced by utilizing such small hydro plants to reduce peak demands.

Like the great majority of small hydro plants, the Niles station was operated with the originally installed manual control equipment. Although in all probability it had paid for itself during its operating life, the constant 24-hour attendance that it required and manual control reduced its economical and functional effectiveness. Conversion to automatic operation reduced operating costs by 75 percent and increased the station's operating efficiency. Experience has shown that the plant can be left unattended except for daily readings and cleaning. The reduction in operating costs alone paid for all of the new equipment and installation charges in less than two years. This does not include additional savings realized from reduced purchase of peak power made possible by the plant's newly injected generating efficiency.

Human element removed

Fully automatic operation, arranged to make the most efficient and economical use of the available water, replaced the plant's manual control. In emergencies it is still possible to control the operation manually.

The machine is arranged so that it starts and stops from water level (float) control with a high and low level float (pre-set).

Normally, the machine is arranged to start and stop by time clock indication, the periods of operation coinciding with the local system load peaks. However, when the water level behind the dam exceeds the predetermined maximum the machine runs continuously until the stored water capacity has dropped to the normal operating range. Also, if the level should drop below this same normal range then the station is taken off automatically and remains inoperative until such time as there is enough water impounded behind the dam to bring it back up to normal. In addition, automatic control of the turbine gate maintains the required opening to carry a preset full load, regardless of water level. This is done by an electric head level control employing a synchro-transmitter operated by a float and a system of levers and a receiver operating upon the gate mechanism.

As part of the modernizing and conversion, it was necessary to modify or change all hand operated equipment and accessories to provide full automatic control. This included operation of the breaker, the brake, voltage control, synchronization, cooling, etc.

An alarm system shuts down equipment when any of fifteen types of trouble develop. The type of trouble is indicated by the proper red lamp being lit and the ringing of two bells: one on the station exterior and the other at the operator's house. These are arranged so that the only point of alarm shut-off is a switch on the alarm panel.

Figure 1 is an exterior view of the station from below the dam. The generator, with a part of its auxiliary equipment, is shown in Figure 2. The direct-connected exciter is mounted at the upper end of the generator shaft. The centrifugal speed switch for protection against over-speed is shown above the exciter. It is connected to the upper end of the exciter shaft by a flexible coupling. The construction is such that before the switch resets the speed of the generator must drop below a preset maximum.

Mounted on the right side of the base are two cabinets, side-by-side. The one on the right contains three current transformers in the neutral end of the generator windings which are used for differential protection. To the left is the electrically controlled field switch with local push button as well as automatic operation and a light mounted on the front to show its operating position without opening the cabinet. Above this is a manual field reversing switch. The solenoid operated brake mechanism and the bearing thermal relays are on the other side and out of sight. The raceway for control wires aids inspection and maintenance.

Figure 3 shows the governor and all of its associated accessories for automatic as well as manual control of the gates. In this same picture at the far right appears the 48-volt control battery, and above it the charger for maintaining the battery voltage.

Breaker is easily accessible

Figures 4 and 5 show the front of the switchgear with the panels both open and closed giving a general idea of the complexity of the control and its layout.

Appearing in the upper left-hand corner of Figure 4 is a separate swinging panel with the automatic synchronizer, the ac ammeter and voltmeter, and their respective transfer switches for connecting the meters individually to the different phases are mounted on the front. The interior of this panel contains the auxiliary relays for the automatic synchronizer. The breaker test cabinet, with facilities for operating the breaker out of the switchgear during the periodic maintenance inspections, is immediately below the swinging panel.

The left-hand unit is for the breaker, shown racked into operating position, the raising crank being inserted in position to lower or raise the circuit breaker. Lying on the floor in front of the unit is the plug jumper used in testing circuit breaker operation while it is in the unit, but arranged so that the main breaker disconnects are open to prevent the closing of the power circuit during testing. Various miscellaneous equipment details can be seen mounted on the interior walls and barriers.

The right-hand unit contains the potential transformers and the station service transformer and their protective fuses, all of which are obscured by the barriers. The protective inner barrier is hinged for access to this equipment. Also in view on the internal barriers of this unit are the annunciator relays, the thermal overcurrent relays, and the automatic time switch. The compact arrangement of the rear of the panels improves operation and maintenance.

Figure 5 shows the same units with the front swinging panels closed. The left-hand panel has the dc ammeter and voltmeter for the field circuit, the generator voltage regulator and its controls, the synchronizing switch and the governor control switch. The main and field breaker control switches and their red and green indicating position indicating lamps, a wattmeter, the differential relays, and the reverse phase relay are also mounted on the left-hand panel.

The right-hand panel has the reverse power relays, overpower relays, exciter over-voltage relay, over-current relays, phase balance relay, a group of auxiliary relays, and timing relays. The annunciator lamps and escutcheon plates, the exciter rheostat mounted on the rear of the panel with its adjusting handle removed and miscellaneous control switches are also mounted on the right-hand panel.

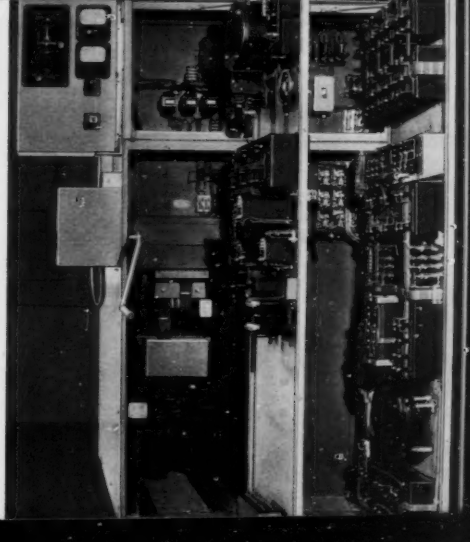
Controls provide complete protection

Figure 6 shows the schematic diagram of connections for the automatic control of this automatic hydro-electric generating station. Simple operation of device 43 shifts the control

AUXILIARY EQUIPMENT for the 432-kva, 4160-volt generator is mounted on the unit for convenience and to save space. **(FIG. 2)**

AUTOMATIC GOVERNOR equipment for the hydro plant opens and closes gates in response to water level changes. **(FIG. 3)**

COMPACT ARRANGEMENT of 150,000-kva switchgear centralizes control, simplifies operation, saves valuable space. **(FIG. 4)**



from manual to full automatic operation and, if water and time conditions are correct, the unit is started, brought up to proper voltage and speed, and automatically synchronized with the rest of the system. The unit then takes load to the predetermined capacity and runs without further attention until normal automatic shut-down time arrives or until shut down and locked out of service by improper operation or failure of one of its components. If locked out, the reason or reasons for such a shut down are indicated by the proper red lamps of the annunciator.

Starting and stopping is done through the activation and deactivation of master relay 3 either by control switch MCS or the time clock contacts in normal operation, or by float switch contacts 163 and 163B through the auxiliary relays 163X and 163BX. Once relay 3 is picked up, it is sealed in by its own contact and stays in until its coil is short-circuited by a shut-down contact. Relay 3, in turn, picks up and drops out master relay 4. It also energizes the electric head level control receiver and transmitter.

Master relay 4 performs several functions. It energizes the field breaker, 41, puts automatic synchronizer 25 in service, lets oil into the mechanism, 65, to open the gate and starts two timing relays. The first of these, 2, cuts out the lock-out and alarm system until the machine has started. The second, 48, shuts down the machine if it fails to go on the line in a reasonable period of time after the starting sequence has begun.

As the gates begin to open, limit switch 33X closes and provides cooling water either from the fore bay or city water supply through solenoid valves 20-1 or 20-2 and starter 20R, if fore bay water is used.

The automatic synchronizer sends impulses to the governor through contacts H1 or H2. When synchronism is reached, contacts R close and breaker 52 closes as a result of the actions of auxiliary relays 52X and 52Y and closing coil 52CC. The governor and head level control enable the machine to take and hold a preset full load.

In shutting down for internal failures detected by differential relays 87, lock-out relay 87X is energized and, in turn, drops out relays 3 and 4. Any other shut-down cause energizes an annunciator relay, such as 49A, which activates a red lamp, rings the bell and causes relay 86 to operate which, in turn, drops out relays 3 and 4. Dropping out of relay 4 trips the main and field breakers and removes oil pressure from the gate mechanisms. Limit switch 33Y energizes timing relay 62 when the gate closes. The timing relay then applies the brakes for a predetermined time and releases them by the action of relay 62X.

In manual operation, automatic synchronizer contacts H1, H2 and R do not operate so that synchronizing has to be done manually. All other functions of manual or automatic stopping and starting are performed by relays 3 and 4.

This operation continues day after day without human intervention or interference being necessary. Of course, routine inspections of all parts of the equipment are always recommended. This, of course, is and can be combined with the periodic visits for recording in the station log sheets of the necessary operating data.

This improved operation costs less than that provided by initially cheaper manual controls. This is true not only of this station but of many others. Economic studies of many existing electrical installations show other instances where various degrees of modernization and conversion to automatic operation provide more efficient and safe operation with considerable savings.

FRONT PANELS contain all the necessary metering, protective and control apparatus arranged for convenient normal operation. Easy accessibility is especially helpful in emergencies. **(FIGURE 5)**

THROUGH THE YEARS..

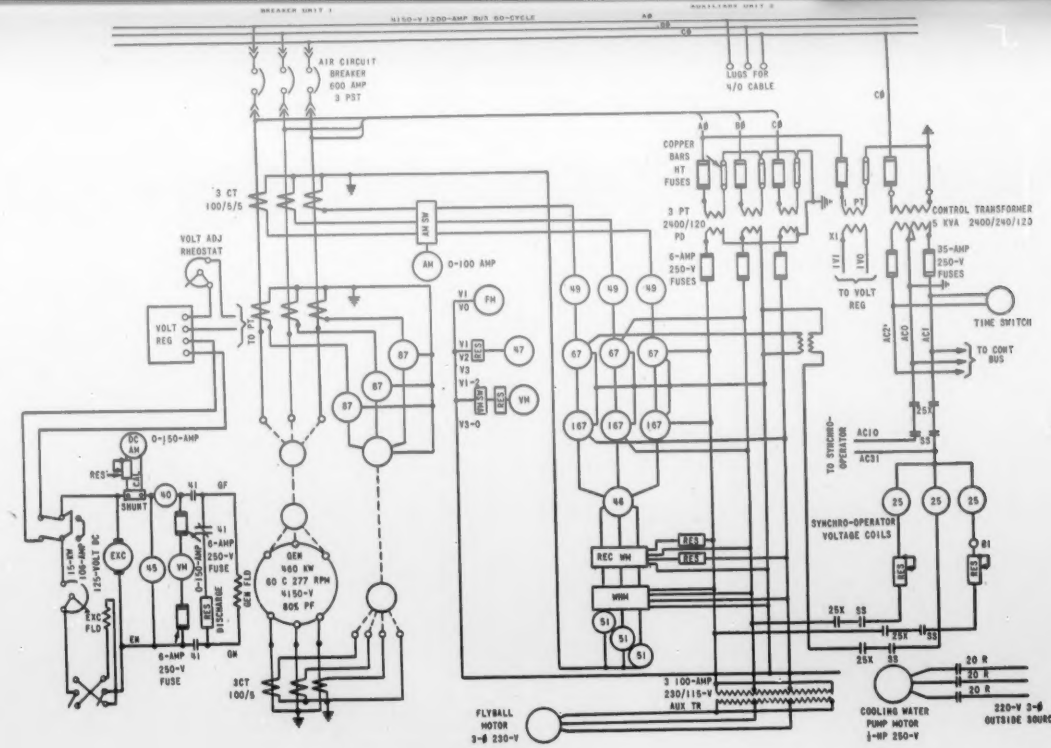
NILES, MICHIGAN, is a typical small American city of well-kept residences and diversified industry. Dowagiac Creek has been providing some sort of power for the community for over a century. A dam and some type of water wheel has been as much of a landmark as the stream itself. The creek furnished power for the first grist mill which was as vital to the people in days gone by as the hydro-electric plant is to the present generation.

The Niles Electric Company was formed in 1892 to provide electricity and street lights for the city. The earth and timber dam and timber flumes were enlarged, and horizontal water wheels and generators were installed. In 1894, the entire plant, including dam and water privileges, was purchased by the city for $37,200. Additional equipment, consisting of one 2,000-candle power incandescent machine complete with necessary station equipment and transformers was purchased in February, 1895. In 1897, according to the first annual report of the Board of Public Works, the city's electrical plant consisted of two 35-light 2,000-candle power arc dynamos, one 50-light 2,000-candle power arc dynamo and one 2,000-light incandescent dynamo.

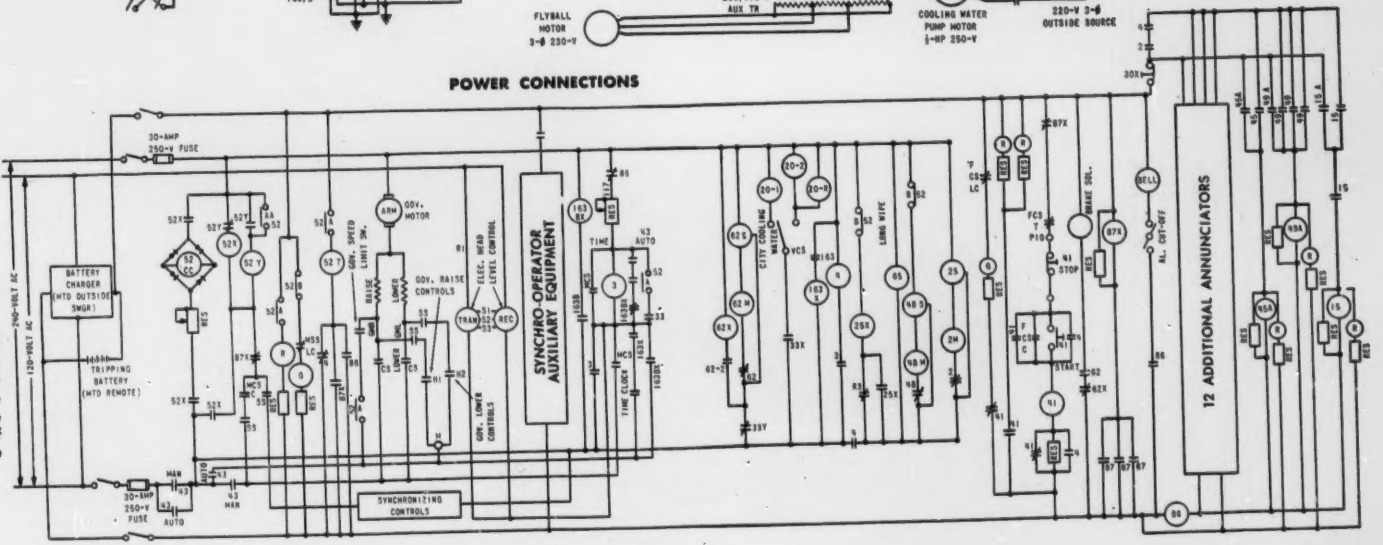
Surging demand for electric power resulted in an agreement between Niles and the Indiana and Michigan Electric Company for additional power. Renewed from time to time this contract is still in effect. At present Niles purchases about 80 percent of its needs from the utility and obtains the other 20 percent from the hydro plant. Being run-of-stream, this plant is used for peaking during low water. Since June, 1934 the load has grown from the purchase of 178,000 kwh, demand of 630 kw and generation of 120,300 kwh to a purchase of 1,026,000 kwh, demand of 3640 kw and generation of 334,200 kwh in June, 1950.

Because of the increased use of electric power, the City of Niles purchased one 300-kw generator to be driven by the horizontal twin turbines which were then in operation. An erection man was hired to install the machine at $6.50 per day plus expenses. In January, 1912 the city paid $3,216.00 which represented 50 percent of the purchase price of two generators! Expansion was necessary again in 1920 when contracts were let for a complete new dam, flumes, powerhouse, and the installation of a vertical water wheel and a 460-kw generator complete with switchboard, governor, etc. Conversion of the plant from manual to automatic control was begun in the summer of 1948 which resulted in the present modern, fully automatic 4-wire, 3-phase, solidly grounded neutral, 2400/4160-volt arrangement.

2 - TIME DELAY RELAY
3 - MASTER RELAY
4 - MASTER CONTACTOR
15 - SPEED SWITCH
25 - SYNCHRO-OPERATOR
25X - SYN-OP DISCONNECT RELAY
33 - GATE LT SW CLOSED AT NO LOAD OR LESS
33X - GATE LT SW OPEN WHEN GATES CLOSED
33Y - GATE LT SW CLOSED WHEN GATES CLOSED
38 - BEARING TEMPERATURE RELAY
40 - FIELD FAILURE RELAY
41 - FIELD SWITCH
43 - MAN-OFF-AUTO SWITCH
45 - EXCITER OVERVOLTAGE RELAY
46 - PHASE CURRENT BALANCE
47 - REV PH-PH FAIL-LOW VOLTAGE
48 - SEQUENCE TIMING RELAY
49 - THERMAL OVERLOAD
51 - INVERSE TIME OVERLOAD RELAY
52 - CIRCUIT BREAKER
62 - BRAKE TIMING RELAY
63 - GOV OIL PRESS FAILURE RELAY
163 - FLOAT SW - OPEN AT LOW WATER LEVEL
163B - FLOAT SW - CLOSED AT HIGH WATER LEVEL
263 - PRESS SW - THRUST BEARING COOLING WATER
65 - GOV INLET VALVE SOLENOID
67 - LOAD LIMIT CONTROL RELAY
167 - REVERSE POWER RELAY
86 - LOCKOUT ANNUNCIATOR RELAY
87 - RATIO DIFFERENTIAL RELAY
87X - RATIO DIFFERENTIAL AUX RELAY
A - ANNUNCIATOR HOLDING RELAYS .
20-1 - SOL WATER VALVE - CITY MAINS
20-2 - SOL WATER VALVE - FOREBAY
20-R - PUMP STARTING RELAY
52CC - CLOSING COIL FOR ACB
52X - CONTROL RELAY FOR ACB
52Y - ANTI-PUMPING RELAY
52T - TRIP COIL
AM - AMMETER
AM SW - AMMETER SWITCH
VM - VOLTMETER
FM - FREQUENCY METER
SS - SYNCHRONIZING SWITCH
WHM - WATTHOUR METER
REC WM - RECORDING WATTMETER
VCS - VALVE CONTROL SWITCH
MCS - CONTROL SW-MAIN BREAKER
FCS - CONTROL SWITCH-FIELD BREAKER
30X - ALARM RESET-PUSH BUTTON
163BX - FLOAT SWITCH AUX RELAY
163X - FLOAT SWITCH AUX RELAY



POWER CONNECTIONS



CONTROL SCHEMATIC

SCHEMATIC DIAGRAM of control and the three line diagram of power connections are accompanied by pertinent NEMA symbols legend shown above. Diagrams show the central metering and protective relaying connections which provide fully automatic or semi-automatic manual operation of the Niles hydro-electric plant. Parts of the synchronizing equipment and portions of the alarm and annunciator system have been omitted. **(FIGURE 6)**

FINAL INSPECTION of 75,000-kva, three-phase, 138,000/13,200-volt, forced-oil cooled transformer is being conducted on test floor prior to shipment for installation at a large midwestern utility.

A-C Staff Photo

24,000-HP DYNAMOMETER

Tests Jet Engines

by **M. GAY*** and **W. F. KING**
Motor-Generator Section and **D. DALASTA**
Switchgear Section
Allis-Chalmers Mfg. Co.

World's largest power-delivering dynamometer provides accurate torque measurement in either direction of rotation.

MODERN TEST FACILITIES recently installed in the Andrew Willgoos turbine laboratory of Pratt-Whitney Aircraft Division, United Aircraft Corporation, permit testing under load major components of the most powerful turbo-jet engines now being built. Special equipment and operating procedures were required to obtain the accurate data necessary for perfecting the design and predicting the performance of the jet engines.

One phase of this particular test facility consists of a 24,000-hp power delivering dynamometer which is capable of transmitting torque to equipment being tested at any speed from 1210 to 15,072 rpm in either direction of rotation. The magnitude of torque being transmitted is determined accurately by directly measuring the torque being developed in the dynamometer. As a result, output power can then be established from the magnitude of torque output of the dynamometer and the speed of the output shaft of the speed increasing gear.

Dynamometer torque is developed by the 24,000-hp, three-phase, 93.3-cycle, 3,000-volt, 10-pole synchronous motor connected to a two-speed ratio gear through a flexible coupling, Figure 1. The particular ratio to be used is selected by a hydraulic gear shifting mechanism. Speed is adjusted by first selecting the desirable gear ratio and secondly by varying the frequency of the generators supplying power to the synchronous drive motor.

This dynamometer is unique because of the method used to obtain a direct measurement of the torque being transmitted from the gear. By having the motor and gear mounted on a single base, which in turn is supported on four hydrostatic bearings, it is possible to obtain a direct measurement of torque.

Oil film reduces friction

Because of the uniqueness of the test facility, nearly all of the major pieces of equipment had to be specially engineered. The features of the dynamometer and the manner in which it was mounted reflect the ingenuity of the engineers in meeting design and mounting requirements for this installation.

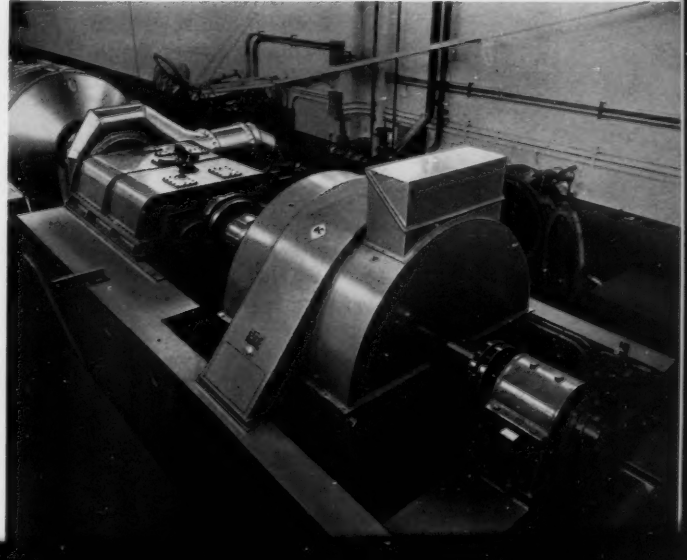
For example, to move a body weighing 130,000 pounds, the weight of 35 automobiles, with one finger is not a Herculean feat but a matter of minimizing frictional resistance. If the body is supported by a fluid, like a log floating in water, there is, obviously, little resistance to movement.

The function of the dynamometer mounting is to permit measurement of the gear output torque with an accuracy of one-half of one percent. It must allow sufficient angular movement of the unit to actuate the torque measuring equipment with very little friction. The angular movement should not affect the shaft alignment. Furthermore, the mounting should be stable in the axial and lateral directions.

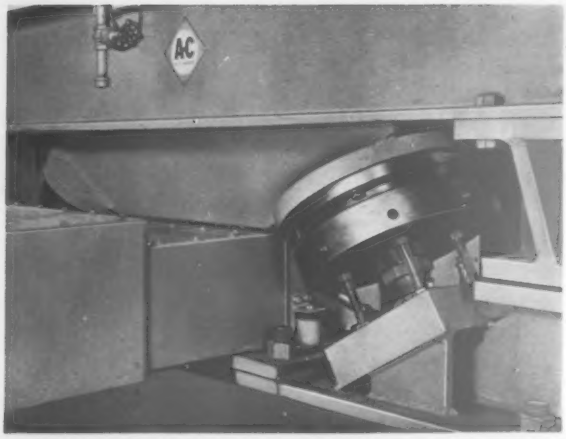
The motor and speed increasing gear are mounted on a common base or cradle, which, in turn, is supported on four radially located spherical pads, two at each end of the cradle. Oil is pumped between the mating spherical surfaces to float the unit on a film of oil. Since the frictional resistance in an oil film is proportional to the velocity, it approaches zero at a very slow rate of movement. The center of gravity of the unit is only

* Authors wish to acknowledge the editorial cooperation of B. A. Schmickrath, chief of experimental test facilities, Pratt-Whitney Aircraft Division, United Aircraft Corporation, East Hartford, Conn.

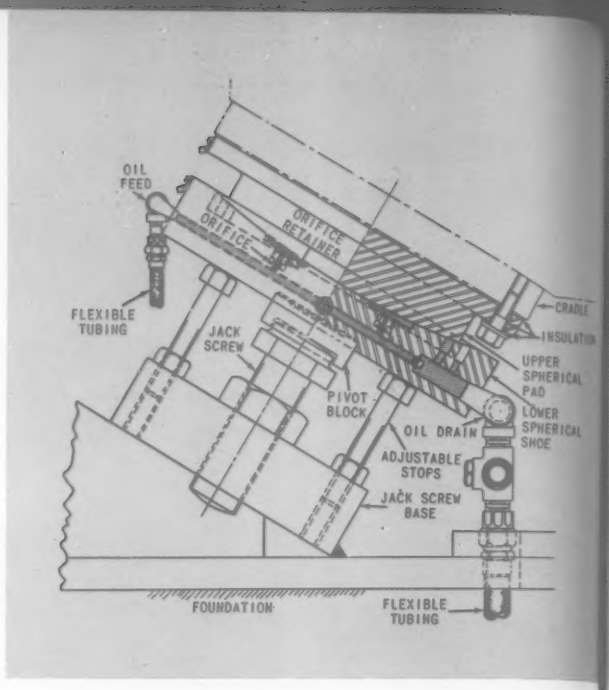
Photos courtesy of Pratt-Whitney Aircraft Division



DYNAMOMETER, its 24,000-hp synchronous motor and two-speed gear are mounted on a single base. This support is cradled on the four hydrostatic bearings. **(FIGURE 1)**



SPHERICAL PADS of one of two hydrostatic bearings mounted on each end of the dynamometer cradling are shown above. Enclosed bus duct is at lower left. **(FIG. 2)**



LINE DRAWING of the hydrostatic spherical bearing assembly shows the component parts. Shaded portion traces the flow of oil through the bearing assembly. **(FIG. 3)**

slightly below the axis of rotation to keep pendulum effect to a minimum and yet return the unit to a position of equilibrium. Torque is measured by a thrust meter which engages an arm extending horizontally from the cradle in line with the shaft center.

The two spherical pads at each end of the cradle, Figure 2, conform to a common spherical surface having a radius of curvature originating at the center line of the shaft. Consequently, rotational movement of the unit will not displace the shaft center to disturb alignment with the driven machine. Machining of the spherical surfaces was performed on an air operated, tracer equipped lathe to master templates producing a surface accurate to 1/1000 of an inch. Mating surfaces were then lapped together to remove tool marks and improve the accuracy of fit.

The upper convex spherical pads shown in Figure 3 are bolted to surfaces on the lower part of the cradle and are accurately machined to obtain correct angular and radial location of the bearing surface. These pads are insulated from the cradle so that the oil film separation can be checked by indicating lights on a low voltage circuit.

Spherical bearings insure accuracy

The lower concave spherical shoe is supported by a central hardened block, pivoted on the hardened, rounded head of a jack screw. This pivoted support insures proper matching of the spherical surfaces while the jack screw provides for vertical and lateral adjustment of the unit. The jack screw base rests on sole plates grouted to the foundation. Tilting of the shoe is limited by four adjustable stops to guard against instability under extraordinary conditions.

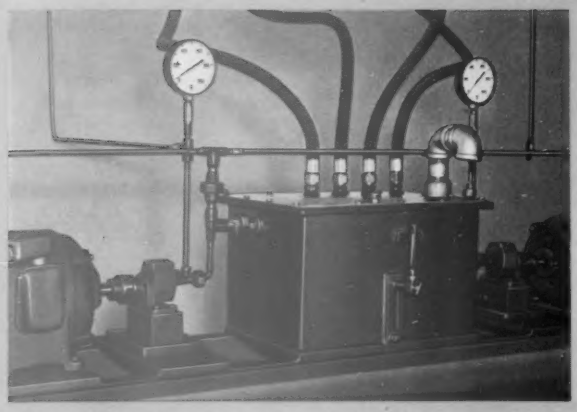
Oil is delivered to each bearing by an individual pump through a flexible hose connection to the lower shoe as shown in Figure 4. Passageways drilled in the shoe admit the oil to the bearing surface through four ports uniformly spaced about the center of the shoe. Orifices located at these ports prevent loss of the oil film separation under abnormal conditions such as mismatching of the spherical surfaces or a surface defect. Since the pressure drop through an orifice would be sixteen times as great if it were to pass the entire supply of oil instead of its normal quota of one-fourth the oil supply, it is easy to design an orifice to control abnormal oil flow without excessive pressure drop under normal conditions.

Oil flowing radially outward from the bearing surface is trapped in two annular grooves in the lower shoe and drained through flexible tubing to the reservoir. The inner groove, which is sealed by the bearing surfaces, collects most of the oil. Seepage beyond the inner groove drains into the outer groove which is outside the upper pad. A drilled hole for the flexible drain line connection at the lower part of the shoe connects with both grooves.

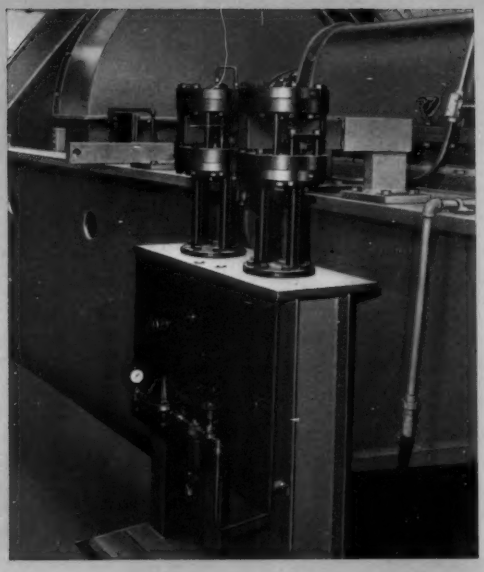
In operation, the bearing surfaces are separated by an oil film approximately 5/1000 of an inch thick. It consists of medium grade oil pumped to each bearing at a pressure of 500 psi at a rate of about one gallon per minute. Since the thickness of the oil film varies as the cube root of the rate of oil delivery and of the oil viscosity, it is insensitive to small changes in those factors. When the performance of the hydrostatic bearings was tested in the shop, it was demonstrated that a force of a few pounds or the pressure of a man's finger on the torque measuring arm was sufficient to cause perceptible rotational movement of the unit. Removal of the force returns the unit to its position of equilibrium. During the test the force was well within the allowable error. A movement at the arm of about 4/1000 of an inch is all that is needed for operation of the force measuring device. With this limit of movement, the pendulum effect due to the center of gravity of the unit being below the axis of rotation causes an error of less than one pound force at the arm. At maximum torque the force measures 2100 pounds. Weights are attached to the cradle to level the unit laterally when it is at rest.

Frame eliminates vibration

Vibration characteristics rather than strength requirements were responsible for the massive proportions of the cradle. To avoid excessive vibration the natural vibration frequencies of the combined cradle and parts mounted upon it, in combination with the rotor shaft, were removed from the operating frequency range of both the motor and gears. These parts, therefore, were designed to have natural frequencies above



HIGH PRESSURE OIL supply system for the hydrostatic bearings consists of two gear pumps, drive motor and oil sump with four hose connections for oil return. **(FIG. 4)**



TORQUE MEASURING equipment is mounted on the end of the torque arm. Panel of double acting, double range device mounts valves and other necessary equipment. **(FIGURE 5)**

the maximum rotational frequency of the motor and below that of the output gear shaft.

The portion of the cradle extending between the motor frame and the gear housing is subjected to the torque transmitted by the motor shaft. To provide ample torsional rigidity, the side members of the cradle were made with a rectangular box cross-section instead of the more conventional I-beam section.

Blocks on the foundation members, under the four corners of the cradle, provide support for the cradle during erection or at other times when it is undesirable to rest the cradle on the spherical bearings. Stops are embodied in the blocks to limit movement of the cradle in case the torque measuring device should be improperly secured. Arms extend from both sides of the cradle for attachment of a weight at a fixed radius for calibrating the torque measuring equipment.

Although slight movement is permitted, the spherical bearings restrain axial movement. Axial shift is limited by an antifriction bearing mounted on a vertical shaft secured to the base and located between two axially spaced plates attached to the lower part of the cradle. Proper spacing of the plates prevents the bearing from contacting both simultaneously.

Dynamometer needs special motor

The dynamometer is driven by a 24,000-hp, 1120-rpm, 93.3-cycle salient pole synchronous motor. This 3000-volt, three-phase, unity power factor motor is designed for a 70-degree C rise measured with stator temperature detectors and an 80-degree C rise in the field when measured with resistance with a continuous load on the motor and with the motor operating in an ambient temperature of 40 degrees C. Stator coil and field windings of the motor are insulated with full class B insulation.

A closed recirculating ventilating system with external blowers, blower motors, an air-to-water heat exchanger, and a plenum chamber, all located in the pit below the dynamometer, provides the necessary cooling. Mounted in the plenum chamber are two 18,392-cfm, 2248-rpm blowers individually driven through V-belt drives from 50-hp, 1760-rpm, 440-volt, three-phase, 60-cycle squirrel cage induction driving motors. The blowers obtain inlet air directly from the plenum chamber and discharge it vertically into separate air ducts located above the chamber. In turn, these two air ducts discharge the air into the two enclosed ends of the synchronous driving motor.

After passing through the motor, the ventilating air is discharged into a duct at the bottom of the motor. This duct is connected to the air-to-water heat exchanger mounted on the plenum chamber. Incorporating cupro-nickel tubes and rolled Naval bronze tube sheets, the heat exchanger with its water connections was laid out specifically for this application. Ducts at the bottom of the driving motor as well as the ducts and heat exchanger above the plenum chamber are joined with flexible connections to prevent the introduction of restraint which would restrict the movement of the dynamometer.

All external connections to the dynamometer had to be quite flexible.

The stator lead bus consists of laminated copper strips extending axially from the cradle. While these leads are deflected, both in bending and in torsion with movement of the cradle, the slight movement involved, together with the flexibility of the leads results in only insignificant resistance to the movement. The rotor field leads are flexible cable. Soft rubber strips attached to the upper part of the air housing and set to a gap of 10/1000 of an inch from the matching surface of the stator connect the air housing and the stator.

Oil lift reduces starting torque

Before starting, the driving motor rotor is lifted in its bearings with high pressure oil to reduce the breakaway torque required for starting. The high pressure oil is supplied by a separate system at each of the two bearing pedestals of the motor. Each of these includes a squirrel cage induction motor, a gear type oil pump, oil sump piping, valves, and pressure switches. The motor starters and pressure switches are interlocked with the starting procedure so that the motor cannot be started until oil pressure has been built up in the bearings. Oil is pumped into a recess in the bearing bushing under the journal with enough pressure to lift the shaft and float it on a film of oil, thereby enabling the rotor to be turned with little effort.

In practice, an individual pump for each bearing delivers oil at the rate of about one gallon per minute. It may develop a pressure of 750 to 900 psi to initially raise the shaft, after which the pressure will drop about 200 psi and the shaft floats on a film of oil about 2/1000 of an inch thick. It can be observed that the hydrodynamic pressure in the oil film during normal operation when the high pressure pumps are shut down is substantially the same as that required to hold the shaft in a lifted position when it is stationary.

During normal operation the spherically seated, pedestal type sleeve bearings of the motor are flood-lubricated from a low pressure lubrication system. Each of the bearing pedestals has oil sumps of sufficient capacity so that the driving motor could be brought to a normal stop without injury to the bearings if the low pressure lube oil system should fail. While bringing the motor to a stop with the low pressure lube oil system inoperative, oil is carried to the bearings from the sump in the pedestal by two oil rings in each of the bearings.

Variable frequency power supply

Power supply for the dynamometer driving motor consists of four turbine-generator sets already installed at the test facility. The electrical characteristics of the power supply and the switchgear had to be specially designed to accommodate the electrical characteristics and rating of the available turbine-generator sets. Since it was desirable to start the dynamometer motor from one of the four turbine-generator sets which had only one-fourth the kva rating of the motor, the motor had to start with a compressor inertia load equivalent to approximately 20 times the motor inertia.

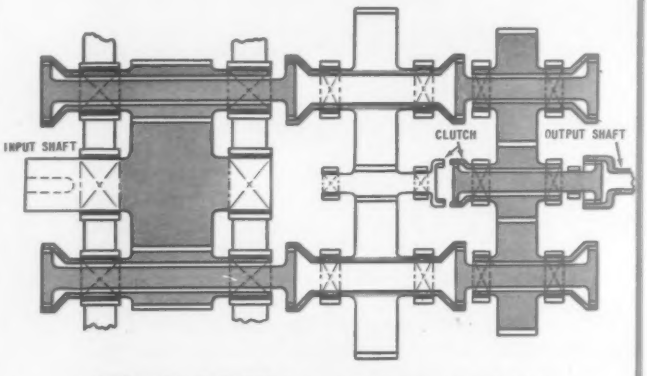
In this particular instance, synchronous starting was the simplest way of starting the dynamometer motor. Tests demonstrated that the high pressure lube oil lift system is so effective in reducing the necessary breakaway torque and the torque characteristics of the motor had been so well correlated with the characteristics of the existing generators that the combined installation is able to start in synchronism with a single generator connected to the dynamometer motor. In starting, the excitation of the generator and of the motor is set at predetermined values. The generator being used is then connected to the motor bus by closing the appropriate generator "motor bus" breaker. Steam is admitted to the turbine after the electrical system has been tied together. As the turbine-generator set accelerates, the dynamometer motor remains synchronized and accelerates with the turbine-generator set.

After the system reaches a speed corresponding to 25 cycles per second, additional generators can be brought up to the 25-cycle-per-second speed and synchronized manually on the motor bus. The number of generators paralleled on the bus is determined on the basis of the power required to run the particular compressor test being contemplated. After the necessary number of generators have been paralleled on the motor bus, the speed of the dynamometer motor can be varied to whatever speeds between 180 and 1120 rpm needed for the compressor test. This speed variation is accomplished by either increasing or decreasing the speed of the turbo-generator sets as needed.

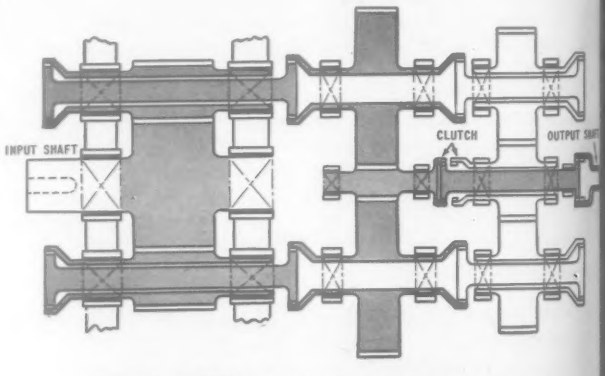
Dual sets of voltmeters and synchroscopes were required. One set is used with frequencies up to 25 cycles and the other set is used at a frequency of 60 cycles per second.

The switchgear is arranged to enable additional turbo-generators to be paralleled electrically prior to starting in the event that a single generator should be unable to start the motor.

An alternate starting method was incorporated in the design of the switchgear and the motor since it was not certain at the start that synchronous starting would be satisfactory in view of the limited power supply, the large compressor inertia, and the need of coordinating motor design with the existing generators. This method consists of bringing the turbo-generator set up to a low speed, setting the generator and motor excitation at predetermined values, closing the generator breaker on the motor bus, and accelerating and synchronizing the motor. After the motor is synchronized, the turbo-generator set and motor are accelerated to a speed corresponding to 25 cycles per second. At this frequency, additional turbo-generator sets are synchronized on the motor bus as required for the particular test being run. The speed of the dynamometer is then adjusted to whatever speeds needed to obtain the required test points by increasing or decreasing the



SCHEMATIC DIAGRAM shows gear arrangement and clutch engagement of speed increasing gear. Shaded portion indicates path of power transmission for low speed ratio. **(FIG. 6)**



SHADED PORTION of schematic illustration of the speed increasing gear indicates the actual path of power transmission used for high speed ratio. **(FIGURE 7)**

speed of the turbo-generator sets. Initial operation of the dynamometer, however, indicated that the primary starting procedure is adequate and that the alternate method will not be necessary.

Hydraulic pressure system measures torque

Torque output of the dynamometer is measured directly and continuously without the necessity of measuring the stress or deformation of a shaft and converting to an equivalent torque. There is also no need of measuring the power input to the dynamometer and subtracting the losses in the dynamometer at the particular torque and speed at which a test is being conducted.

The magnitude of the torque is obtained from the force at the end of the dynamometer torque arm shown in Figure 5 which is needed to balance the torque developed in the dynamometer. The balancing force consists of hydraulic pressure acting on the surface of flexible diaphragms at the end of the torque arm. If this hydraulic force is not great enough to balance the force at the end of the torque arm resulting from the torque developed in the dynamometer, a very small angular rotation of the dynamometer occurs which operates a poppet valve and admits more pressure to the diaphragm until the forces are again balanced and the angular position of the dynamometer is again restored to its neutral position.

If the force is too great and a slight angular rotation occurs in the opposite direction, some of the pressure is exhausted until a state of equilibrium is again attained. A damping mechanism is incorporated in the torque measuring equipment to prevent instability between the two opposing forces. Since it is necessary to measure torque in either direction of rotation, torque measuring mechanisms are placed both above and below the end of the torque arm to make the torque measuring equipment double acting. Because the dynamometer has two speed ratios and, consequently, two rated torque outputs, it is necessary to use two double acting torque measuring mechanisms. Only one of these is used when the gear is in the high output speed-low output torque gear ratio. Both of the double-acting mechanisms are used when the gear is in the low speed-high output torque gear ratio. When both mechanisms are used, one of them acts as the master control to control hydraulic pressure and the other serves as a receiver operating from pressure from the master.

A system of solenoid operated valves selects the proper diaphragm for the particular direction of rotation of the dynamometer. These also select either single or dual operation for the particular gear ratio being used.

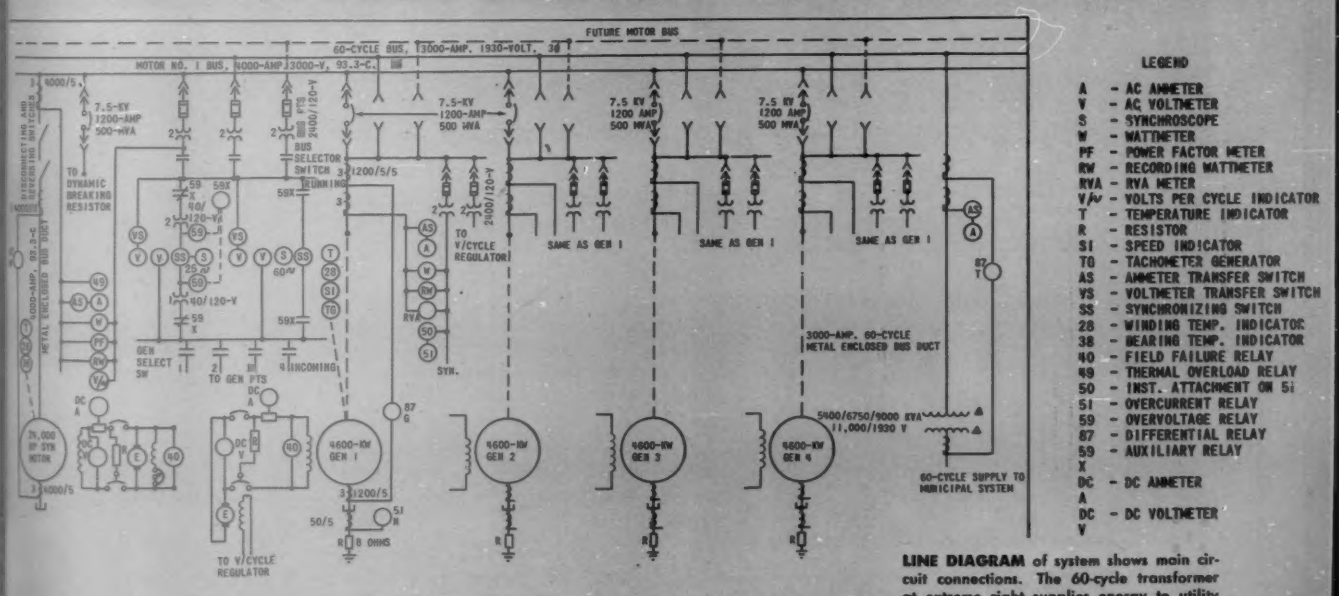
Measurement of torque magnitude is obtained by having the pressure in the diaphragms of the torque measuring device position indicated on a sensitive pressure gauge.

Gear permits wide speed range

The dynamometer incorporates a speed increasing gear with two gear ratios. A set of low speed gears and two separate sets of high speed gears having different ratios provide the means for doubling the range of speed of the dynamometer. A hydraulically actuated shifting device enables the pinions of either one of the two sets of high speed gears to be coupled to the output shaft. With an input speed of 1120 rpm, one set of high speed gears has an output speed of 7528 rpm while the other set has an output speed of 15,072 rpm. The gear is rated 21,500 hp at an output speed of 7528 rpm and 18,000 hp at the top output speed of 15,072 rpm. The gear is of the divided train type with the horsepower input divided equally between two identical intermediate assemblies which are coupled to the high speed gears by quill shafts and involute tooth couplings. The gear combinations and clutch engagements used to obtain the low and high gear ratios respectively are shown schematically in Figure 6 and Figure 7.

The hydraulic shifting mechanism can be operated only when the dynamometer is not running. Hydraulic pressure is used to move a piston connected to a toothed element of the clutch which engages an internally toothed element of the clutch on either the high or low ratio high speed gear train. Pressure switches and a safety lock in the shifting mechanism indicate whether or not satisfactory pressure is available and to assure that the mechanism does not shift during operation. The gear also has its own lubrication system.

Gear oil is supplied through a flexible connection and drained through a telescoping connection. Only one set of



LINE DIAGRAM of system shows main circuit connections. The 60-cycle transformer at extreme right supplies energy to utility lines during non-test periods. **(FIGURE 8)**

external oil connections is needed for the oil since the motor bearings are supplied from and drained into the gear case.

Switchgear and control specially designed

Like the 24,000-hp power delivering dynamometer and auxiliary machines, the switchgear and control equipment required unusual departure from that normally supplied for ordinary synchronous motors and generators. Basically, the switchgear and control system had to:

1. Utilize four 4600-kw, 5600-rpm, 3000-volt, unity power factor, three-phase, 93.3-cycle generators which originally had a different rating as destroyer escort vessel propulsion generators and are used now to accelerate and drive one 24,000-hp, 3,000-volt, three-phase, 93.3-cycle power delivering dynamometer at a variable frequency up to 93.3 cycles maximum.
2. Provide means to utilize the output of these generators to supply 60-cycle energy for other purposes when the full capacity of the supply generators is in excess of the dynamometer requirements.
3. Provide a flexible arrangement so that expansion to include a second dynamometer was possible with a minimum of additional switching equipment and without expensive equipment modifications.
4. Provide switching scheme suitable for operation of any combination of the three loads simultaneously by energy supplied from any combination of generators.

Three bus scheme chosen

The triple-bus scheme shown by the single line diagram, Figure 8, was selected as the most satisfactory means to meet the basic requirements. The 3000-volt metal-clad switchgear is designed for the final installation of three complete three-phase buses running throughout the length of the switchgear. The initial installation is made with only two of these buses, one a 4000-amp, 93.3-cycle bus for the 24,000-hp dynamometer, and the second a 3000-amp, 60-cycle bus for 60-cycle supply to a nearby municipal power system. Provision is included for the addition of a third bus for a possible future dynamometer.

Each 4600-kw generator can be connected to the 24,000-hp dynamometer bus through a 1200-amp, 500,000-kva interrupting capacity vertical lift air blast circuit breaker. Three circuit breaker units are provided for each generator circuit for connection to any of the three main buses. These units are located side by side with only one removable circuit breaker element, which, when inserted into the appropriate structure, allows the generator to be connected to the desired bus.

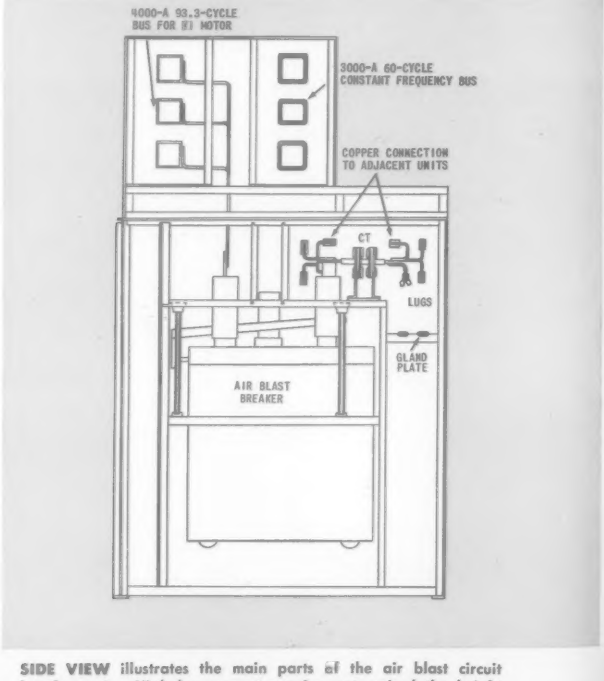
A special 42-inch wide metal-clad auxiliary unit at one end of the switchgear lineup encloses the dynamometer disconnecting and reversing switches. One additional circuit breaker unit is provided for connection to the dynamic breaking resistor for the 24,000-hp dynamometer. Three potential transformer auxiliary units are necessary, one for each two generators and one for the three sets of bus potential transformers.

The air blast circuit breakers are rated 7.5 kv, 1200 amp, 500 mva ic at rated voltage. Since magnetic blow-out coils such as those commonly used with air magnetic breakers are not used, the variable operating frequency does not materially concern the effectiveness of these air blast breakers. Due to the high interrupting and momentary short circuit ampere requirements, 4.16-kv rated circuit breakers were too small so that 7.5-kv breakers were necessary. A special extra capacity air supply unit for circuit breaker operation is required to provide the excessive number of operations normally encountered in a test facility of this type.

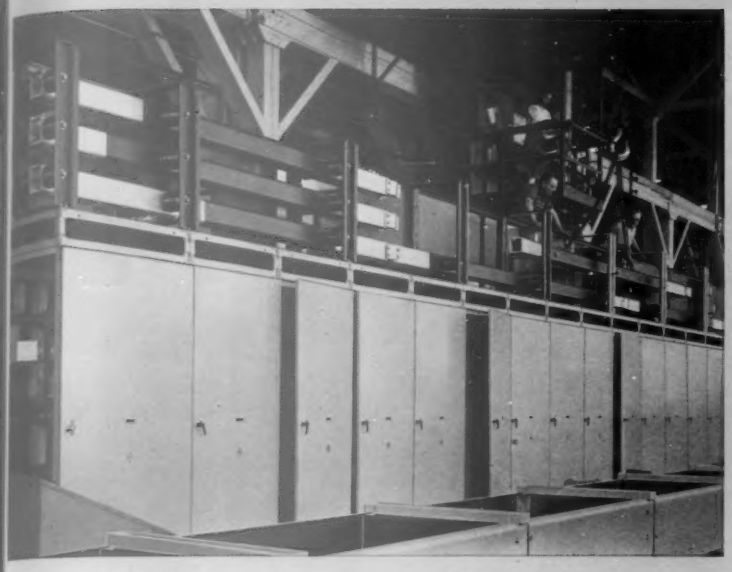
Local testing of the circuit breakers at the individual circuit breaker units is made possible by mounting a close-trip push button station integral with the standard plug jumper device furnished as an accessory with the 3-kv switchgear.

The dynamometer is disconnected from its switchgear bus by three spst, 4000-amp individually hook-stick operated

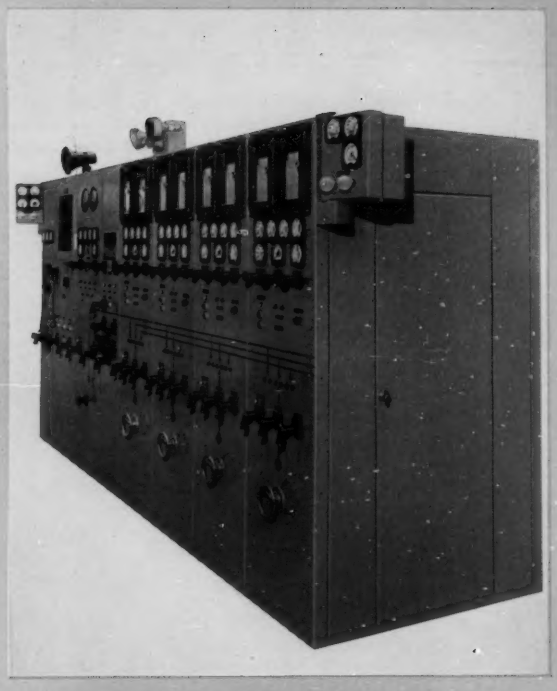
SQUARE, HOLLOW copper conductors of the 4,000-amp bus duct are ventilated and painted black to reduce temperature rise. Duct extends from the switchgear to the 24,000-hp motor. **(FIG. 9)**



SIDE VIEW illustrates the main parts of the air blast circuit breaker unit. High bus current requirements raised the height of the switchgear unit to 136½ inches. **(FIGURE 10)**



BUS COPPER of the 4,000-amp bus is set into special superstructures. Left end unit houses disconnecting switches and connects to the 24,000-hp dynamometer through the floor. **(FIG. 11)**



FOUR FRONT PANELS (right) of the duplex control board contain controls for each of the four generators. Motor, annunciator and city tie panels are at the left end. **(FIGURE 12)**

disconnecting switches. Two additional switches are provided for reversing purposes. All five switches are mounted in a single auxiliary unit with positive mechanical interlocks to prevent short circuiting the bus by operational errors.

Variable frequency bus

The 4000 ampere connection between the switchgear and the dynamometer consists of approximately 150 feet of metal enclosed bus duct. The bus duct is rated 5 kv, 4000 amp, 93.3 cycles and is constructed to withstand mechanical stresses resulting from a three-phase short circuit of 60,000 amperes momentary. All insulators are made of porcelain and are rated 7.5 kv.

One 6-inch by ¼-inch square hollow ventilated copper tube is provided for each phase and assembled in 18-foot lengths, with provision for expansion at each 18-foot interval. An all aluminum enclosure was required for non-magnetic construction because of the large currents and special frequency involved. Completely insulated joints at each six-foot interval assists in minimizing lateral circulating currents. Dust proof construction is obtained by felt gasketing throughout. Figure 9 shows a portion of this bus duct after final assembly.

Due to the high current buses, the standard metal-clad switchgear units required modification to accommodate two large bus housings and also provide suitable provision for a future main bus. Since the normal bus location is near the top of the unit, this modification was made by increasing the height of the unit from 92 inches to 136½ inches while maintaining standard widths and depths. The dimensions and arrangement of these bus housings are identical to the metal enclosed bus duct external to the switchgear except for such minor details as covers. A cross-section sketch of a circuit breaker unit indicating the bus arrangement is shown by Figure 10.

Figure 11 shows the buses being installed by crane in their housings on top of the circuit breaker units.

Indicating, metering, relaying and control devices for the electrical system are mounted on a metal enclosed tunnel type duplex control board. All electrical operations are performed at this point except for several push button stations and other local control devices. Figure 12 shows the control board.

Dual sets of voltmeters and synchroscopes for synchronizing of generators at approximately 25 cycles and at 60 cycles are included. All synchronizing equipment is designed to be done manually.

The original rotating type voltage regulators furnished with the generators for marine service were utilized. This consisted of the rotating generator element mounted integrally with the original motor-generator excitation set and the control element and other devices which were dismounted from their original boards and relocated on the duplex control board. Some of the auxiliary resistors were located in the low voltage metal enclosed switchgear which houses the field circuit breakers for the four generators and the dynamometer.

The regulator is designed to control the generator voltage as a function of the frequency and to hold approximately 32.2 constant volts per cycle. For manual regulation, a manual-automatic transfer switch, an exciter field rheostat and a volts-per-cycle indicator connected to the dynamometer bus potential transformers are provided.

In addition to the governor control switches for individual generators, three separate master governor control switches were furnished for the three main three-phase buses. These master switches are connected to act uniformly on all turbines driving generators connected to the respective buses. Operation of one individual governor control switch automatically commands control and relinquishes control only when this switch is returned to normal.

Complications due to variable frequencies

Due to the frequency range of operation, special care was necessary to preclude the use of any instrument, meter, or relay

beyond the frequency range of its design. Standard devices were utilized to the maximum extent possible but in some cases modifications or additional equipment became imperative.

For synchronizing purposes, all three sets of bus potential transformer secondaries were connected together to form a running bus, and similarly connected generator potential transformers formed an incoming bus. By operation of bus and generator selector switches, the proper bus and the proper generator to be synchronized can be applied to these incoming and running buses.

Synchronizing at 25 cycles introduced complications in that auxiliary step-up transformers were necessary to boost the potential transformer secondary voltages to a value which fell within the range of operation of the synchroscope. These auxiliary potential transformers are disconnected through the use of an overvoltage relay to protect against the higher voltages resulting as the frequency increased up to the 93.3-cycle (3000-volt) maximum. A second set of instruments with synchroscope are included for 60-cycle synchronizing. These are suitable for the full operating voltage up to 150 volts on the potential transformer secondaries.

Protective relays were in general not seriously affected by the frequency range. The instantaneous trip elements on the overcurrent relays supplement the induction elements which were ineffective at lower frequencies. Generator and motor differential, and thermal overload relays are of the standard types.

Most indicating instruments have a frequency range of approximately 15 to 125 cycles which covers the frequency range of this application. The synchroscope phase shifting reactors were discarded and three-phase potential was applied to provide a wider frequency range for synchronizing purposes.

Protection against abnormal operation

Protection for the motor during operation is provided by 10-ohm resistance temperature detectors imbedded in the stator coil slots, temperature relays that shut off the motor at a predetermined bearing temperature, pedestal bearing temperature detectors for bearing temperature indication and recording and an overspeed switch that initiates a stop with dynamic braking if the dynamometer should be driven an overspeed by the equipment being tested. These devices as well as the pressure switches in the lubrication systems, interlocks on the auxiliary motor starters, a tachometer generator for speed indication and recording, hydrostatic bearing oil film contact switch, and gear bearing temperature detectors provide necessary protection and operating control. All of them transmit respective signals to the switchgear and control equipment that control operation and record operating results.

The relaying scheme is shown on the single line diagram. Each generator is provided with overcurrent relays with instantaneous attachments, differential protection, and a residual overcurrent relay which is connected to the 50/5 current transformer in the neutral grounding resistor circuit.

The 24,000-hp dynamometer circuit includes differential, thermal overload, and field failure protection.

The dynamometer bearing temperature relays and the drive gear 16-point temperature recorder are each provided with high and low contacts. The low contacts are incorporated in the annunciator system while the high contacts initiate shut-down.

The protective system differentiates between electrical and mechanical faults. Electrical faults cause general shut-down without the application of dynamic braking. Mechanical fault protective devices apply dynamic braking in addition to general shut-down.

Auxiliary equipment and devices supplied with the major items of equipment includes a motor excitation motor-generator set, tachometer generator, overspeed switch, and dynamic braking resistor.

The excitation motor-generator set that supplies excitation to the dynamometer motor is of standard construction with a 60-kw, 125-volt, 1750-rpm compound wound dc generator driven by a 100-hp, 440-volt, three-phase, 60-cycle, 1750-rpm squirrel cage induction motor.

The dynamic braking resistor, Figure 13, consists of 60 boxes of grid resistors with proper resistance and heat dissipating capacity to absorb the energy of the rotating mass in the dynamometer and the equipment being tested. It is capable of braking the system in one minute from maximum speed with the expected maximum amount of inertia that may be present in the equipment to be tested.

Successful design and operation of the dynamometer and other specially designed equipment in the test facility represents the results of cooperation and free exchange of ideas by the principals in an effort to solve an unprecedented problem. The accuracy of data obtained in this unusual installation provides the assurance that turbo-jet aircraft engines will have the desirable performance characteristics.

DYNAMIC BRAKING resistor used with cradle-mounted dynamometer absorbs the tremendous rotating energy of the 24,000-hp synchronous motor and its connected load. Resistor unit consists of 60 boxes of standard grid resistors. **(FIGURE 13)**

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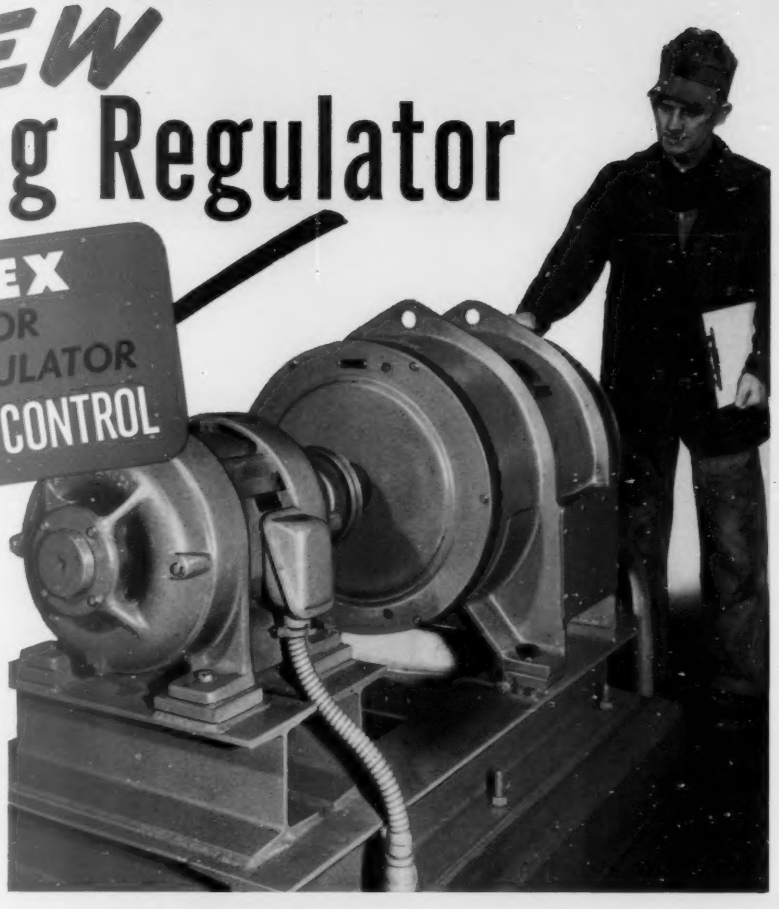

1 Minimizes the effect of disturbances caused by sudden load changes and fault conditions.

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3 Provides proper division of reactive current between synchronous machines operating in parallel when a cross current compensator is applied.

4 Provides accurate, sensitive voltage control.

5 Functions without hunting.

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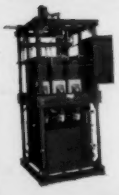

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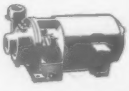

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